INVESTIGATION OF THE BARIUM ENEMA X-RAY EXAMINATION AS A SIGNIFICANT CONTRIBUTOR TO THE GENETICALLY-SIGNIFICANT DOSE FROM DIAGNOSTIC RADIOLOGY

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Dedication

To Colin and Nicola; and

to my mother and father

ABSTRACT

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The results of a study conducted by Maree (1995) indicated that the genetically-significant dose (GSD) for the white, female population in South Africa was considerably higher than the GSD for females in Great Britain, France and the United States of America. Further to this finding, Maree's study demonstrated that the barium enema x-ray examination was the major contributor to the GSD for this population group. A study of barium enema examinations was embarked on in order to explain the findings of Maree.

The study was designed to include dose-area product measurements on patients having the barium enema procedure. In addition patient data and technique factors were recorded. The x-ray equipment used for the investigation was one digital and two non-digital fluoroscopic systems in the Western Cape. The digital unit utilised an overhead tube as did one of the conventional units. The other unit had an undercouch fluoroscopic tube and an overhead tube used for the standard radiography views.

Comparison of the dose-area product measurements demonstrated that the unit having an undercouch tube had a mean dose-area product of 99.69 Gy cm^2 which culminates in a higher dose to the patient than the equipment utilising an overhead tube. The mean dose-area product of the two units with an overhead tube was 56.57 Gy cm^2 and 51.94 Gy cm^2 respectively.

Free Air Exposure tables based on "RADCOMP Entrance Skin Exposure Software Program" (Nuclear Associates and Zamenhof, 1990) were used together with average technique factors to calculate skin entrance doses. These skin entrance doses were used to calculate gonad doses with the aid of a computer program from the Food and Drug Administration in the USA (Peterson and Rosenstein, 1989).

The results were compared with the results of the barium enema component of the research conducted by Maree. The comparison indicated an average gonad dose for males of 242 $\mu Gy \times 10^{-1}$ (present study) compared to 485 $\mu Gy \times 10^{-1}$ (Maree) and an average gonad dose for females of 11185 $\mu Gy \times 10^{-1}$ (present study) compared to 16111 $\mu Gy \times 10^{-1}$ (Maree).

Air-kerma at skin entrance was calculated using dose-area product measurements, recorded during the present study, for individual exposures and screening. These values were used to calculate the gonad dose. A discrepancy was demonstrated

between the calculation of gonad dose from calculated as opposed measured skin entrance dose. The average gonad dose calculated by Maree is 16111 μGy x 10^{-1} and the average gonad dose calculated for the present study using the measured skin entrance dose is 4236 μGy x 10^{-1}. This seems to explain the larger GSD estimated by Maree for the white female patients.

A national protocol for measuring patient doses from x-ray examinations is proposed for South Africa.

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CONTENTS

Chapter 1

INTRODUCTION

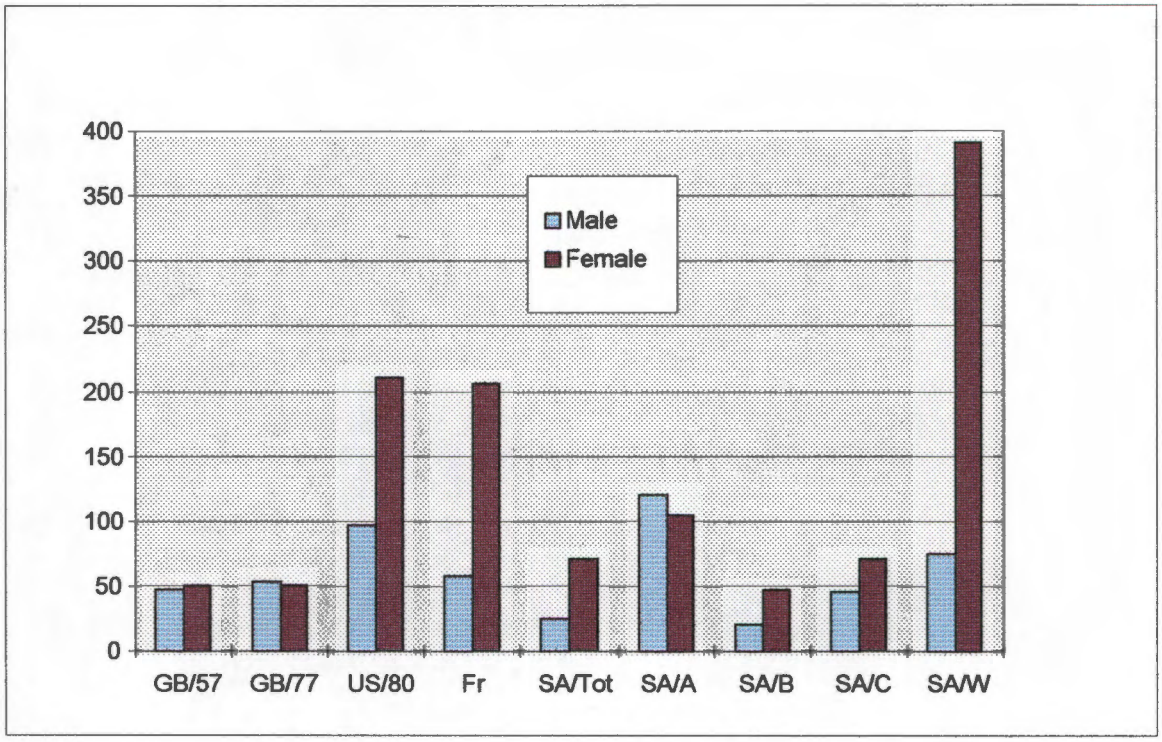
The research done by Maree on the determination of the genetically-significant dose (GSD) from Diagnostic Radiology for the South African population, 1990-1991, included the calculation of the contribution to the GSD of each gender in four race groups in South Africa (Maree, 1995). These results were compared with the GSD results of three first world countries and it was demonstrated that the contribution to the GSD from the white race, female gender for the South African (SA) population was significantly higher than the GSD for females in Great Britain, France and the United States of America as is shown in Figure 1.1. According to Maree the contribution of the SA white female population to the GSD is five times that of the SA white males, it is also five times that of the total SA female population, almost twice that of the female population of France and the United States and more than seven times that of the female population of Great Britain. These results were an indication that further investigation was needed.

Maree also found that there were a small number of examinations per thousand population (Figure 1.2), as well a small GSD for the Black population (Figure 1.1), when compared to the other three race groups in S A.

In Maree's study it is noted that the examination frequency is higher, per thousand population, for the male groups than for the female groups (Figure 1.2). However, when the GSD is considered the opposite was demonstrated (Figure 1.1). The phenomenon of the contribution of females to the GSD being higher than that of males, in most instances, can be attributed to the fact that there is a higher gonad dose to women in the majority of the examinations (Maree, 1995). The variation in the anatomical position of the male and female gonads explains this result.

Maree (Figure 1.3) graphically represents the contribution of the various x-ray examinations to the GSD for White females (Maree, 1995). This demonstrates that the barium enema (Ba E) was the major contributor to the GSD for white females in South Africa. Wall *et al* (1984) discussed data from two surveys done in Great Britain during 1957 (Adrian, 1960) and 1964 (Matthews *et al,* 1969) . These surveys demonstrated that Ba Es were amongst the nine examinations which contributed to about 95 per cent of the GSD. Wall further showed that the Ba E examination contributed 1.2% and 4% to the GSD respectively, in the two studies (Wall *et al,* 1984) . A further survey of 1977, also discussed by Wall, involved the measurement of entrance skin dose at the level of the ovaries with Thermoluminescent Dosimeters (TLDs). These measurements were converted to ovarian doses using conversion factors obtained by exposing an anthropomorphic phantom. The results showed an increase in the mean ovarian dose from Ba Es, in females, of more than a factor of three from the Adrian survey of 1957. The relative contribution of the Ba E examination to the GSD of females was shown to be 6.7%. Ba Es are considered to have increased in importance due to the increased complexity of the study, namely the introduction of the double contrast technique, resulting in a higher ovarian dose per examination (Wall *et al,* 1984).

Figure 1.1: *Contribution by gender to the GSD in μGy* (Maree, 1995)



GB/57 : Great Britain, 1957
GB/77 : Great Britain, 1977
US/80 : United States of America, 1980
Fr : France
SA/Tot: South Africa/Total population
SA/A : South Africa/Asian population
SA/B : South Africa/Black population
SA/C : South Africa/Coloured population
SA/W : South Africa/White population

Figure 1.2: *Number of examinations per thousand population for the race-gender groups in South Africa* (Maree, 1995)

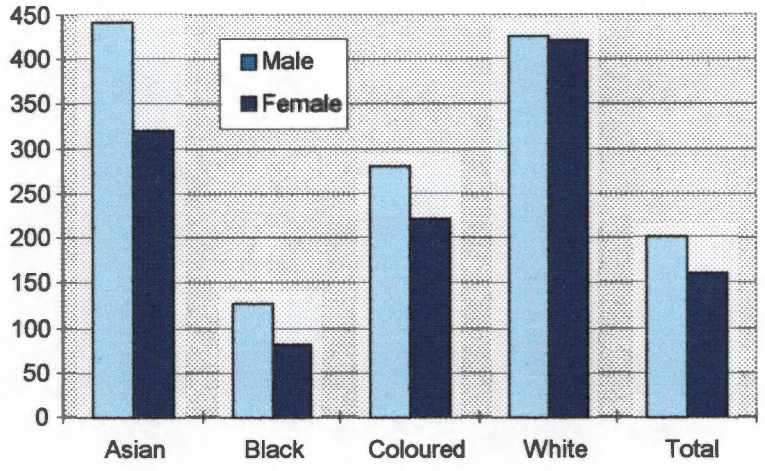
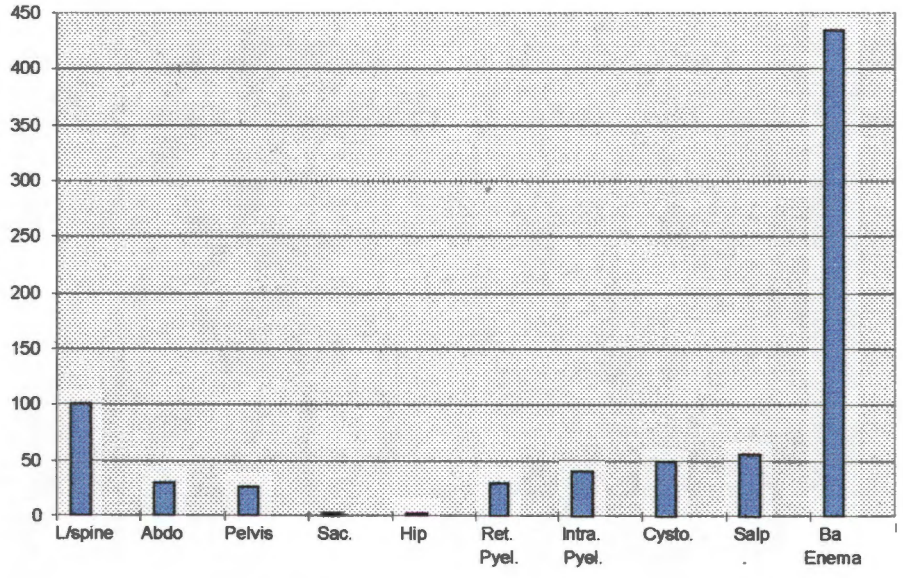


Figure 1.3: *Contribution of various examinations of White females to the GSD in μGy* (Maree, 1995)



A further study in Great Britain, during 1983/84, recorded the effective dose equivalent (EDE) for the 10 most significant diagnostic radiology examinations, as regards radiation risk. This study showed that the Ba E had the highest EDE of 7.7 mSv (Shrimpton *et al*, 1986). Hall confirms that the largest contributors to the GSD, for females, are lumbar spine and Ba E investigations (Hall,1994). It has also been stated by Burniston that the percentage of the patient population presenting for Ba E examinations will increase. This projected increase in Ba Es is a result of the reduction in premature death and the commensurate increase in the older population group most at risk of contracting colo-rectal/intestinal carcinoma (Burniston, 1993). It is also a widely held opinion that the use of the Ba E has and will continue to decline in favour of the colonoscopy. This investigation provides an alternative method of examining the colon (Gelfand, 1996). The colonoscopy has certain advantages discussed by Gelfand and in addition there is no radiation risk involved which could favourably affect the GSD. However there are clearly disadvantages when the colonoscopy is compared to the Ba E such that this procedure will not be likely to take over from the Ba E completely. The Ba E will remain the examination of choice in many circumstances (Gelfand, 1996).

It is recommended that dose measurements are made on the radiographic images or procedures that make a significant contribution to the collective population dose from medical x-ray examinations (IPSM, 1992). The results of the studies mentioned above demonstrate that the Ba E x-ray examination is a significant procedure when considering dose in diagnostic radiology. It was thus decided that a closer study of this particular procedure was warranted and would assist in the attempt to explain the disparity in the GSD of the white female population of South Africa as compared to other groups in this as well as other countries.

Maccia *et al* (1988) in his investigation of doses to patients from diagnostic radiology in France related the effective collective dose equivalent for France to 5 other countries. Significant differences were shown with Great Britain having a lower value than France by a factor of 6. Maccia goes on to say that three different factors may help to explain the discrepancy. The first is the number of examinations carried out per 1 000 in the population, the second is the type of radiological technique used in performing the same type of examination and finally the pathology which the radiologists are seeking has an impact on the exposure (Maccia *et al*, 1988). These factors are beyond the realm of this study, however they will have an impact on the GSD result of Maree and will contribute to the high value for South Africa as compared Great Britain the United States and France (Figure 1.1). The fact that the UK uses medical x-rays far less frequently than many other developed countries, with about half the number of x-ray examination per head of population as compared to the USA or France (NRPB, 1990), may be part of the explanation of the higher value in South Africa as compared to the UK.

The current investigation of the barium enema x-ray examination involved:

1. Analysis of the data from the work of Maree for this particular procedure.

2. Measurement of dose in Gy cm^2 to patients having this examination, using a dose-area product meter (DAP-meter).

3. Comparison of the dose measurements and other relevant data obtained in this study to measurements and data recorded by Maree and researchers in other countries.

4. The provision of extensive dose-data for the barium enema, not available previously, which will represent a useful base line against which future measurements may be compared.

5. Comparisons were made of the skin entrance doses (free in air) and gonad doses of Maree (1995) and conclusions were drawn from this comparison.

6. Recommendations for the establishment of a National Protocol for South Africa, including reference doses for significant x-ray examinations.

The small number of examinations per thousand population as well as the small GSD of the Black population can be attributed to socio-economic reasons (Maree, 1995). Basic medical care is not readily available for the low income groups, especially for people in rural areas. Specialised diagnostic radiology is, therefore, even less likely to be carried out on a large scale. As medical care in South Africa is extended more equitably it is expected that specialised medicine will include more of the presently under-serviced communities. The GSD of the Black population could be expected to increase commensurately.

Chapter 2

RADIATION DOSIMETRY

It is generally considered that the radiation dose from medical exposure is equal to approximately half the exposure from natural sources of ionising radiation (Maccia, 1988). It may also be as high as 90% of the radiation dose to the population, from all sources other than natural background radiation (IPSM, 1992) . There should be considerable effort given to reducing this medical exposure and a useful tool in the attempt to reduce the dose is the knowledge of the radiation doses received by patients undergoing x-ray examinations. The safe use of x-rays should be a concern of all who use ionising radiation to procure an image for diagnostic purposes. If it is assumed that safety is risk related and that risk is dose related, it is necessary to have a standard system of measurement for the radiation doses which patients receive during medical exposure (Roberts, 1992). Dosimetry plays a pivotal role in establishing the potential for reducing the dose to patients and for identifying the most effective ways of reducing dose (Wall, 1996).

2.1 ABSORBED DOSE

Radiation exposure causes ionisation and excitation of the atoms in the medium through which it travels. Energy will then be deposited in the medium (Bushong, 1991). The ionisation of air can be used for the detection and measurement of ionising radiation such as x-rays and γ-rays (Gifford, 1984).

Ball stated that the effect of radiation on tissue is approximately proportional to the amount of energy absorbed by the tissue and that it is therefore useful to measure the energy transferred from the radiation source to the body tissue in order to have an indication of the radiation effect to the person irradiated (Ball *et al*, 1994).

The deposition of energy transferred from ionising radiation to the material it is travelling through is known as the radiation absorbed dose, or simply absorbed dose (Bushong, 1991). The general definition of absorbed dose is the energy absorbed per unit mass of the medium. The SI unit of absorbed dose is the gray (Gy) which represents one joule of energy absorbed per unit mass of tissue.

$$1\text{Gy} = 1\ \text{J/kg}$$

When doing dose measurements one can use dose, expressed in Gy, or dose-rate which is the absorbed dose per unit time (Gy/s) (Ball *et al*, 1994). Dose-rate is, for example, of interest for fluoroscopy procedures which are a component of the total dose from a Ba E (Gifford, 1984).

The measurement of absorbed dose to the patient during a radiology examination should be done for each view in standard radiography. The measurement, however, should include repeat radiographs so that the dose measured reflects that which was received in order to obtain a diagnostic quality image (Wade, 1994).

The measurement of absorbed dose for an examination which involves screening and standard radiography, such as the Ba E, would require that the measurement is conducted over the entire procedure.

2.2 DOSE MEASUREMENT

In the clinical situation it is not possible to measure the quantity of energy absorbed in tissue due to the exposure of the body to radiation directly. An estimation of the value of absorbed dose is determined indirectly by using one of the effects of radiation which can more easily be measured (Ball *et al*, 1994). Examples of various methods which are relevant to this study are:

1. Dosimetry based upon the ionisation of air.
2. Thermoluminescent dosimetry.
3. Calculation of dose from air kerma or other tube output data.

It is essential that the correct physical quantities are measured and that an appropriate method of measuring or calculating absorbed dose is selected for the given situation. The above methods will be considered in turn.

2.2.1 Ionisation of air

Air in its normal state is a good electrical insulator because it contains molecules that are not charged. When air is exposed to radiation some of the photons of radiation release electrons from the atoms in the air. This ionisation process results in the ability of the air to conduct electricity. A greater exposure results in a larger number of ionisations and thus the amount of charge that can be measured increases accordingly (Ball *et al*, 1994).

The intensity of an x- or γ-ray beam can be obtained by the measurement of the quantity of charge on the ions produced in unit mass of air, called exposure. The SI unit of radiation exposure is the coulomb per kilogram [C/kg]. The C/kg is defined as the radiation exposure which results in a total positive or negative ion charge of 1 coulomb per kilogram of dry air (Ball *et al*, 1994).

The exposure measurement can be related to a value of absorbed dose in air since the average energy required to liberate an ion pair in air is almost constant for all electron energies. This means that if air is exposed to Y roentgens the air kerma, D_{air}, is given by:

$$D_{air} = Y \times 8.69 \text{ mGy}$$

(Suleiman *et al*, 1997)

The dose to the centre of a small mass of unit density air-like material introduced into the air will not require further correction for the energy ranges in diagnostic radiology.

The absorbed dose (gray) = exposure (coulombs per kg) x conversion factor. This conversion factor varies according to the irradiated material (Ball *et al*, 1994).

In the NCRP report No. 102 it is stated that in diagnostic radiology, because the energy of the photon-generated electrons is transferred to air very near the point of radiation interaction, air kerma (Kinetic Energy Released per unit Mass) can be assumed to have a similar value to the absorbed dose in air. Kerma is defined as the sum of the initial kinetic energies per unit mass of all charged particles produced by the radiation (Cember, 1996). It can be used to describe the radiation field either in the presence or the absence of a patient. The SI unit of air kerma is also the gray, where 1 Gy represents a transfer of 1 joule of energy from the x-ray beam per kilogram of air (NCRP, 1989).

The dosimeters which utilise the effect of the ionisation of air by radiation have an ionisation chamber as the radiation sensitive device. There are many different kinds of ionisation chambers. However, they all work on the basic principle of the detection and measurement of the ionisation of air. Two kinds of ionisation chambers which are used in the clinical situation are the 'thimble' ionisation chamber and the dose-area product meter (DAP-meter). These will be discussed in turn.

2.2.1.1 Thimble ionisation chamber

The thimble chamber uses a relatively small volume of air. Air equivalent materials, which have a similar effective atomic number to air but are much more dense, are used in the manufacture of the walls of the chamber (Ball *et al*, 1994). This allows the chamber to behave as if it has a much greater volume of air than is actually present and therefore the size of the chamber can be greatly reduced which makes its use in the clinical situation feasible. Examples of such air equivalent materials are, a mixture of bakelite and graphite or plastic coated with a layer of graphite (Gifford, 1984). Graphite is included to make the wall into an electrical conductor so that it can be used as part of the electrical circuit which is required to collect the ions liberated by the exposure to radiation (Ball *et al*,1994).

Ball *et al* described a thimble ionisation chamber as a chamber where the central electrode is a thin rod of aluminium. This electrode is the other part of the ion collecting circuit. The chamber wall has a negative charge and the central electrode a positive charge. Electrons released inside the chamber are collected on the central rod which is held in position by an insulating seal which ensures that the electrodes are electrically insulated

from each other. The chamber is connected to an electrical measuring instrument and power supply by a cable (Ball *et al*, 1994). Thimble ionisation chambers are available in a large range of shapes and sizes, depending on the purpose for which they are to be used. They are calibrated by reference to a free air ionisation chamber (Ball *et al*, 1994). The ionisation chamber can be used to measure total exposure. In this case the charge collected on the central electrode is stored on a capacitor. This collected charge is measured and the total exposure in coulombs per kilogram is read off on a scale (Ball *et al*, 1994). This exposure measurement can be converted to absorbed dose by the use of a conversion factor which is appropriated for the material and radiation energy. The chamber can also be used as a dose rate meter to measure the exposure produced in unit time. In this case the charge collected per second by the central electrode is found by measuring the electric current flowing in the circuit (charge/time = current). The exposure rate in coulombs per kilogram per second can be read off on the scale and converted to an absorbed dose rate in gray per second by using a conversion factor (Ball *et al*, 1994).

In the past thimble chambers were not commonly used in diagnostic radiology as the instruments were not sensitive to the low energy ranges and low photon flux. These days there are thimble ionisation chambers produced that are highly sensitive and that are virtually constant over the x-ray energy range used in diagnostic radiography.

2.2.1.2 Dose-area product meter

The DAP-meter is used to measure dose-area product of an ionising radiation beam. Measurements are made using a transmission ionisation chamber attached to the diaphragm housing of the x-ray tube (Wall, 1996). A dose area product meter consists of a flat parallel plate ionisation chamber of the order of $15cm^2$ which is transparent to allow the light beam diaphragm device to still be used. The chamber is designed to be mounted on the light beam diaphragm. The use of cones, field delineators and external beam filters require some amendment to the positioning. The chamber is connected to an electrometer and display unit by a long cable which allows for the display unit to be placed in an accessible position. This enables the operator to have easy access to read the dose-area product and reset the equipment to zero.

According to the charge collected by the chamber, the reading of the DAP-meter is the product of the area of the chamber that is exposed to the primary x-ray beam and the average dose in that area. It is essentially an integration of the absorbed dose over the whole beam area for the total exposure to the patient. This means that a DAP-meter can provide a single measurement of the total amount of radiation in even the most complex examinations involving radiography and fluoroscopy (IPSM,1992).

The chamber should be set up perpendicular to and centred on the x-ray beam axis, such that the beam area will never exceed the area of the chamber. These criteria are easily met when the chamber is attached to the diaphragm housing of the x-ray tube. This is the ideal position for the dose-area product chamber as it does not interfere with the examination and is unlikely to receive significant backscattered radiation from the patient (IPSM, 1992). The fact that the reading of a DAP-meter is proportional to the product of the beam area and the dose, which is the same for all planes normal to the beam axis means that it can be mounted well away from the patient and close to the tube focus where the area of the x-ray beam is relatively small and the dose rates are at the highest.

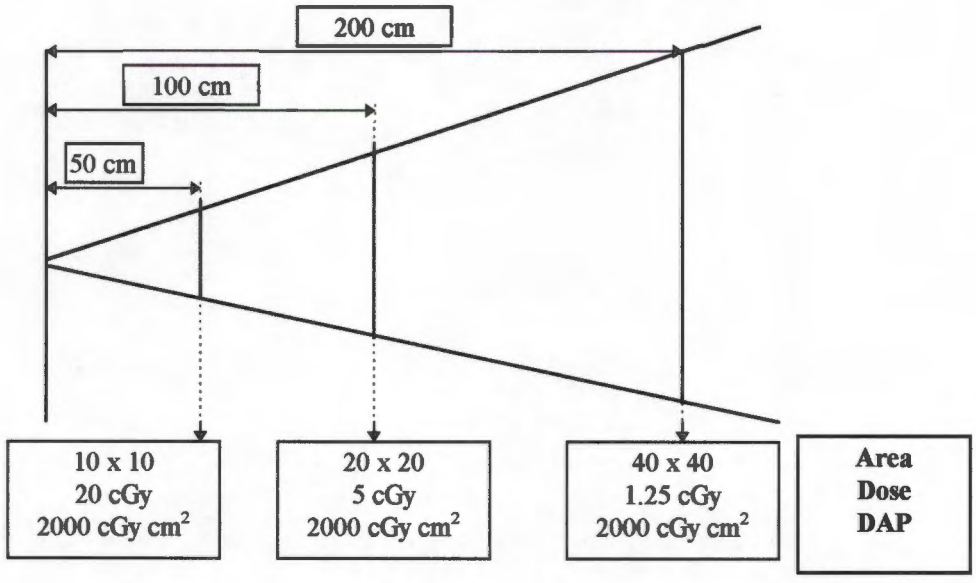
The intensity of the radiation (ie the energy flowing through unit area per unit time) decreases with increasing distance from the source. The relationship between the intensity and the distance from the source is an inverse square law provided that the reduction in intensity is due only to the geometrical divergence and not to any absorption or scattering of the radiation. So too does the area of the radiation beam increase with the square of the distance from the source (Figure 2.1). This means that although the measurement is made at the level of the light beam diaphragm, the product of dose and area will be the same as at the surface of the patient.

The quantity being measured by the DAP-meter is the absorbed dose in air (air kerma) multiplied by the area of the x-ray beam. The SI unit for dose-area product measurements done with this dosemeter is Gy cm^2. The dose-area product was defined as the absorbed dose to air (or the air kerma) averaged over the area of the x-ray beam in a plane perpendicular to the beam axis, multiplied by the area of the beam in the same plane (Hart, Jones *et al,* 1994). In this quantity, radiation backscattered from the patient is excluded. Dose-area product can therefore be measured at any level between the diaphragm housing of the x-ray tube and the patient providing the place of measurement is not close enough to the patient to receive significant backscattered radiation. (IPSM, 1992).

The dose meter must be calibrated for a range of measured field sizes, kVps, doses and dose rates. The calibration must cover both fluoroscopy and radiography modes for diagnostic energies, and be made against a dosemeter calibrated by the CSIR against a "free air" chamber. Most dose area product meters include a timer which, if present, will need to be checked for accuracy. The calibration must be done when the dosemeter is first received and annually thereafter. As the calibration is accurate for the specific equipment in use it is preferable to calibrate the dose area product meter in situ. If the dosemeter is moved to another x-ray unit then the calibration should be checked again at installation. In a situation where the chamber is used undercouch, the calibration should be adjusted for the

couch attenuation so that the readings taken need no further corrections when data is being processed. Alternatively a correction factor can be measured for the couch attenuation and this can be applied to the readings in order to obtain the correct dose. The DAP-meter uses an ionisation chamber so temperature and pressure corrections must be made.

Figure 2.1: *Diagrammatic representation of dose-area product variation with distance*



During a procedure involving more than one radiograph of different areas and also fluoroscopy, the effective x-ray beam moves over a relatively large area of the patient. The total dose-area product summed over all views and fluoroscopy is a better measure of patient dose than entrance surface dose (Hart, Jones *et al*, 1994). This is because the DAP-meter integrates the total exposure throughout a study even if the beam position and beam area change continuously (Hart, Haggett *et al*, 1994). The dose area product meter is therefore highly suitable for the measurement of dose from the Ba E x-ray examination and was the dosemeter of choice for this study.

2.2.2 Thermoluminescent dosimetry

There are some crystals that are able to store the radiation energy absorbed when they are exposed to ionising radiation (Ball *et al*, 1994). Examples of TLDs used in diagnostic radiology are those made of lithium fluoride or lithium borate. Lithium borate has a flatter energy response and better tissue equivalence but is not as sensitive as the more commonly used lithium fluoride (LiF) (Wade, 1994). LiF has a regular crystalline structure, but with the addition of impurities imperfections arise in the lattice. These imperfections give rise to energy traps. When the material is irradiated the energy is absorbed from the radiation beam; some of the electrons of the crystals are raised to higher energy levels. Most of the electrons immediately return to the ground state, but some remain trapped in the impurity levels. Upon subsequent heating of the LiF, these trapped electrons are elevated to still higher electron levels from which they can return to the ground state with the emission of light. (Johns *et al*, 1983). The light emitted is measured with a sensitive photocell. Radiation exposure, which has been found to be directly proportional to the amount of the light emitted, can then be measured and the absorbed dose calculated.

Thermoluminescent dosimeters (TLDs) are usually used in the form of finely powdered lithium fluoride in a solid matrix of Teflon. These are available as small rods or discs (Ball *et al*, 1994). The discs are small and commonly in the region of 3 mm square and less than 1 mm thick. As the TLDs are sensitive to ultraviolet light they are sealed in black polythene sachets before use (Wade, 1994). These rods and discs are reusable as the heating process returns the electrons back to their original levels.

TLDs are ideal for general dosimetry surveys and for personnel monitoring. TLDs can also be used for measuring radiation doses to patients. In this case the dosimeters are stuck onto a patient or even inserted into a body cavity. However, TLDs are unlikely to ever replace ionisation chambers which offer a high degree of accuracy and greater simplicity of use.

TLDs are more commonly used to measure entrance surface dose. The dose to other parts of the body are then calculated from these skin doses. They are suitable for dosimetry in the simple x-ray procedures which involve only plain radiography. The discs are placed directly onto the surface of the patient and left

there for the radiology procedure. They are thin and approximately tissue equivalent (with a similar atomic number) hence they do not usually show up on the radiographic images (Wade, 1994).

The TLDs must be calibrated for typical diagnostic energies against a dose meter with a traceable calibration and should include measurement of the energy response and a check of the linearity of the dose response over the dose range to be encountered. An assessment of the accuracy of the measurements must be carried out and this will indicate the minimum doses which can be measured with confidence (Wade, 1994).

There are many potential sources of error in the use of TLD which are discussed by McKinlay (1981) as follows:

1. There are variations in thermoluminescence characteristics due the phosphor and the manufacturing process of the dosemeter. The selection of a phosphor suitable for the energy range is a consideration although today the use of appropriate filters and phosphors means that a dosemeter can be selected which is approximately energy-independent from 30 kV to 10 MeV x-rays (Cember, 1996). This means that TLD is a suitable method of dosimetry for radiology. The dosemeter design must also be suited to the purpose for which it is to be used. Once the most suitable TLD is selected the inherent variations are outside the control of the user.

2. All phosphors display some changes in their thermoluminescence characteristics according to the thermal treatment they receive. It is therefore essential that all dosemeters are identically annealed to standardise their sensitivities and backgrounds. This process is complex and requires suitable equipment and quality control.

3. Many aspects of the storage and handling of dosemeters can affect the sensitivity, stability, precision and minimum detectable absorbed dose. These can essentially be divided into environmental and physical handling factors.

    3.1 Environmental factors include temperature, humidity, ultraviolet and visible radiation. Care needs to be taken to ensure that the dosemeters are not exposed to temperatures much above normal ambient temperature in storage and use as this can result in thermal fading. Dosemeters, particularly those which are affected by humidity, should be stored with a desiccating agent when not in use and sealed in suitable containers for use. Many phosphors respond to normal ambient levels of ultraviolet and visible radiation. The effect can be the production of a light induced thermoluminescent signal that is followed by the phototransfer and subsequent retrapping of trapped charge carriers. The effect of this can result in increased fading of the dosimetry traps or a transfer of electrons to the dosimetry traps which results in an apparent increase in the recorded signal. TLDs must be packaged in light-tight

packaging to avoid these effects and ambient lighting levels should be reduced in areas where the dosemeters are handled or processed outside their protective covering.

3.2 Physical handling factors include sieving, dispensing, picking up, cleaning and sterilising. The use of powder dosemeters means that the dispensing of the selected mass of powder is the responsibility of the user. This means that each sample of phosphor should be weighed immediately before readout and the result corrected for weight variation. A reproducibility of better than 1% is claimed for most powder dispensers. Solid form dosemeters such as discs or rods obviates this potential error provided they are carefully handled. It was shown that an extruded-ribbon dosemeter could lose up to 25% of its sensitivity over 50 cycles if roughly handled with steel forceps (Cox *et al, 1976)*. Only 3% of this loss was due to weight loss and the remainder was due to tiny scratches causing opacity and loss of sensitivity. It is important to keep dosemeters clean and to remove any dust or grease before it is burned permanently into the surface.

3.3 Dosemeters for clinical use must be packaged to protect them from the effects of contact with skin moisture and grease and also from the often highly photoluminescent adhesives used in the tapes if the TLDs are taped onto the patient.

4. The unintentional release of electrons trapped in the various trapping levels is termed fading. The fading process is complex however, with the application of the appropriate pre-irradiation anneal and post-irradiation pre-read, the apparent fading of the stored signal and thermoluminescence transfer may be reduced to a negligible minimum for all practical absorbed dose measurement purposes.

5. The dosemeters must be calibrated against a known source and exposure. The measurement of absorbed dose to a patient should match the calibration conditions as closely as possible in view of the difficulties of calculating the relative response of TLDs over a range of energies. All dosemeters must also be read out under identical conditions for the readings to be valid.

6. The basis for TLD is the comparison of thermoluminescent light signals from dosemeters exposed to an unknown absorbed dose of radiation, with those from similar dosemeters which have been given a calibration absorbed dose, it is essential that the reader is used in a reproducible way.

6.1 There must be good thermal contact between the phosphor and the heating tray so that the heating rate is constant and the phosphor reaches the readout temperature.

6.2 The effects shown as a series of extra non-radiation-induced glow peaks and the resultant uncertainties in background signal can severely limit the threshold of detection of dosemeters. Suppression of chemiluminescence is reduced by clean handling while triboluminescence is increased by any form of mechanical disturbance. Both effects are related to the surface and are generally greater for dosemeters with high surface area to volume ratios. Readout in an inert atmosphere almost entirely eliminates these effects.

The use of TLDs is generally limited to single exposure radiology and the more complex procedures are not suited to this method of dosimetry. This is because in addition to the above mentioned potential errors there are further problems related to the use of TLD in for example the Ba E.

1. The TLD chips must be placed onto the patient and kept there for the full duration of the examination so as to avoid extreme inconvenience to the patient and staff caused by the option of re-positioning the chips during the examination. As the area of interest changes throughout the procedure the positioning of the chips is difficult and a large number of dosemeters are needed in order to obtain the same information as that obtained from a dose area product meter.

2. Time is a factor and this is particularly so when measuring in a busy x-ray department and the private sector. The use of TLDs is time consuming while the use of a DAP-meter is simple and does not extend the time of the examination at all. In addition the patient suffers no inconvenience and a simple explanation that dose measurements are being done suffices.

All the above factors resulted in the DAP-meter being selected for this study as it was found to be a more suitable dosemeter for the measurement of dose to the patient from a Ba E than the TLD method. It is also a more suitable method of dose measurement if in the future the routine monitoring of x-ray procedures is introduced in South Africa as is the case in the United Kingdom.

2.2.3 Dose Calculations

Entrance surface doses can be calculated from known information of x-ray tube output measurements and knowledge of the exposure settings used (Wall, 1996). This could, for example, involve the calculation of skin doses from the air kerma measurements and information on average patient exposure factors (Wade, 1994). Doses to other organs or parts of the body can be calculated from the skin doses. Several medical physics departments have developed software to do this and there are commercial packages available.

This is a useful method of obtaining absorbed dose measurements for the patient in diagnostic radiology. However it must be cautioned that there is the potential for large errors using this method. Wade participated in a project which compared TLD dose measurements with skin doses calculated from average exposure factors and measured air kerma. The ratio of measured dose divided by calculated dose for AP abdomens ranged from 0.6 to 2.6 (Wade, 1994).

Chapter 3

RADIATION PROTECTION

In November of 1895 Wilhelm Roentgen discovered x-rays. Roentgen was diligent in his investigation of the behaviour of these new-found rays and he established their physical characteristics almost fully within a short period (Maree, 1995). It was however, the tragedy of the radiation pioneers that drew attention to the fact that these x-rays were not only wonderful and useful in medicine, but harmful too. Reports of radiodermatitis, some requiring surgery, came soon after the discovery. However, it took some 30 years before radiation protection measures and the concept of a limit to the exposure dose for radiation workers was established (Maree,1995).

According to Bushong the radiation effects to the patient were considered much later. It was in the 1950s that scientific reports started to be published that implicated the low levels of radiation exposure used in diagnostic radiology in the late radiation responses in patients. The radiation protection regulations of today are based on concern for late effects of radiation to patients and radiation workers. These effects can follow low dose exposure and the latent period is often several years. Late effects can be genetic and somatic effects. The late effects of concern are leukaemia, other malignancies and genetic effects(Bushong, 1991). The health effects that are expected from low levels of exposure will not be observable in the short term. The delay will often be many years and in addition they will usually not be distinguishable from similar effects arising from other causes. This makes it difficult to pin-point their origin, however there is adequate evidence of the harmful effects of low dose radiation (NRPB, 1990).

In the case of medical exposure to radiation, it is useful to consider the genetic and somatic risks separately. This is because the small somatic risk from an x-ray examination can be justified because of the benefit to the patient from an accurate diagnosis being made. However, the genetic risk cannot be as easily off-set. In this case, the direct benefit to the descendants of the person is not likely to balance against the increased chance of an inherited mutation, however small this chance may be (Wall *et al*, 1980). Patients who are within the reproductive age and who have their gonads exposed to x-rays have a risk of inducing severe hereditary disease which is estimated at 2% per gray to the gonads of either parent (NRPB, 1990).

The problem with ionising radiation is that there is no absolute evidence that the smallest doses do not cause damage to cells which might later lead to malignancy or genetic effects if the cells irradiated are the germ cells in the gonads. Therefore we have to assume that the probability of radiation induced cancer or serious hereditary defects is proportional to the radiation dose right down to the lowest levels (Wall, 1996). Late effects of low dose radiation exposure are considered to have no dose threshold and to be linear. This dose-response relationship suggests that no radiation dose, however low, can be considered to be absolutely safe. Although this may be an overestimation of the true radiation effects, at low dose levels, it is preferable to hold to the model and it is the basis for the radiation protection standards of today (Bushong, 1991).

Wall derived probability coefficients for typical radiation doses of some common x-ray examinations and the results indicated a relatively low level of risk of fatal cancer and the hereditary risk was lower still. The Ba E study was at the top end of the scale but still, in his opinion, represented a low risk. However it was stated that all reasonable steps should still be taken to minimise this risk (Wall, 1996). The NRPB also published a probability of radiation effect occurring per million as a result of typical doses from common x-ray examinations. The doses and risks apply to complete examinations with average numbers of films and fluoroscopy times. The Ba E was rated as having a probability of radiation effect occurring (per million) of 26 for maternal irradiation and 5.4 for paternal irradiation. What was also stressed was the cumulative effect of radiation which implies that the risk factor is also cumulative. Everything must therefore be done to reduce the radiation dose and thereby reduce the risk (NRPB, 1990).

Although doses in radiology are low and the chance of late effect is minimal, it is generally accepted that radiation exposure to the radiation workers and the patient should be *As Low As Reasonably Achievable* (ALARA). In the UK this has for reasons of legal precedent been amended to read ALARP - *As Low as Reasonably Practicable.* The two are essentially the same for all practical purposes (Webb, 1984). The radiation protection control of radiation workers is generally excellent and well controlled but in the case of the patient this is not as clear cut.

The potential benefit to the health care of patients can be substantial if the x-ray examination done is correctly indicated. This benefit must not be unduly compromised by excessive attention to radiation protection as it is frequently the case that the radiation risks are insignificant compared to the risks of not obtaining accurate diagnostic information. The problem arises, though, of how the benefit versus the risk can be evaluated (Wall, 1996).

The justification of a practice leading to medical exposure should follow the principle that no practice involving exposure to radiation should be done unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes. For diagnostic medical practices it is not a simple task to quantify the benefit and radiation detriment. It is usually the case that the diagnostic medical exposures are justified merely by demonstrating that there is a valid clinical benefit to the patient and no attempt is made to weigh this against the radiation detriment (Shrimpton *et al,*, 1993). The risk-benefit equation is hard for somatic effects but that much harder when considering genetic effects because those who receive the benefits and those who have a risk are not the same individual. The matter of gain to the patient from the examination generally excuses concern for the radiation dose and this is because so long as there is a real and tangible immediate benefit to the person or society, the small risk is acceptable (Hall, 1994). The question has to be asked though, whether the minimising of radiation dose to the patient is taken seriously enough. Is it always considered whether the examination is necessary and then is the procedure conducted in such a way that the ALARA principle is adhered to?

The National Radiological Protection Board of Great Britain recommends that all diagnostic practices should be justified. This would involve the correct assessment of the

clinical indications for the requested examination, the expected yield from the examination and the way in which the results could be expected to influence the diagnosis and subsequent medical management of the patient. The expected clinical benefit must be such that it will offset the radiation detriment (Shrimpton *et al*, 1993). It has been reported that in a well justified series of Ba E examinations, justification being determined by the degree of symptoms suffered, only 30% of the examinations will be positive. This may seem a low return and indicate that too many people are subjected to the procedure. However the conclusion drawn was that the examination is well justified and that a negative finding is a positive result (Burniston, 1993).

The genetic or hereditary effects of radiation are the result of damage to the germ cells (ova and sperm). This damage is mutation of the hereditary material of the reproductive cells that affects later generations. As genetic effects occur only when the reproductive cells are irradiated, it is essential that the gonads of the patients are shielded during radiology procedures whenever possible (Maree, 1995). In certain examinations it is possible to shield an area within the radiation beam without negatively affecting the diagnostic value of the procedure. Gonad shielding is a good example of this and should always be used in patients with child-bearing potential when it will not compromise the diagnosis. Gonad shielding reduces the dose to the reproductive organs to almost zero (Bushong, 1991). The Ba E procedure does not permit the use of gonad shielding without loss of diagnostic value and it is therefore very infrequently used in this examination. In the survey by Maree gonad shielding was recorded as being used in only one 19 year old male out of the total of 217 patients (Maree, 1995). Gonad shielding was therefore not a consideration for this study and will not be further mentioned.

In 1906 two French scientists theorised and observed that radiosensitivity of cells was a function of the metabolic rate of the tissue being irradiated. This is known as the Law of Bergonie and Tribondeau and has been confirmed many times (Travis, 1989). The germ cells of the gonads are stem cells, which have a high metabolic rate, and are highly radiosensitive (Hall, 1994). This is of key interest in the GSD and in fact to radiation dose to patients within child-bearing age.

The response to radiation of biological tissue is essentially determined by the amount of energy deposited per unit mass. In diagnostic radiology the main interest is to estimate the response at low radiation doses. Radiobiology studies have been conducted to establish the effects of low-dose irradiation. It is not possible to do this directly and the studies have extrapolated the dose-response relationship from the high-dose, known region into the low-dose, unknown region of the curves. This results in a linear, non-threshold dose-response relationship (Hall,1994).

3.1 PATIENT DOSE

Shrimpton *et al* discuss that diagnostic x-ray procedures will involve either full or partial irradiation of the radiosensitive organs of the body. The direct measurement of doses to these organs is only possible for the superficial, compact organs such as the breast or thyroid. Dosemeters located on the patient's skin, in the vicinity of these organs, will allow adequate estimation of the mean dose to the

organ. Doses to the organs deeper in the body or more widely distributed, can only be estimated indirectly, by use of a suitable model, from skin dose measurements. The application of such calculations is difficult for the complex procedures which include radiography and fluoroscopy as it is impossible to specify the position and size of the x-ray beam at each point of the study. This means that the indirect methods necessary for most estimates of organ dose inevitably lead to significant uncertainties. All such uncertainties are difficult to quantify. However, the importance of many of these sources of error will be reduced if large numbers of measurements are done on a heterogeneous population of patients, with ranges of physique and conducted in several radiology departments. It is believed that these circumstances will yield mean values of calculated organ doses that are representative of those for an average adult patient (Shrimpton *et al*, 1986).

It must be stressed that all sources that provide information on dose estimates, for a given x-ray examination, can be grossly misleading for the individual patient and they are no substitute for dose measurement if accuracy is necessary. This is because equipment and techniques vary enormously from institution to institution and in addition the patient variations also effect dose considerably (Hall, 1994). In diagnostic radiology there is a need to measure patient doses because x-rays are potentially harmful. The dose measurement is used as an indication of radiation risk or can be used to calculate an estimate of risk. As diagnostic radiology involves partial body exposures the selection of a dose index suitable for all types of examinations is difficult (Le Heron, 1992).

It was stated by Le Heron that the dose received by the patient during x-ray examinations can be expressed as the entrance surface dose (skin dose), gonad dose, bone marrow dose or organ dose. However these dose indexes are not considered to be very satisfactory as total radiation risk indicators. The concept of effective dose equivalent was extended from use with radiation workers and the index, effective dose, was adopted as a dose index of radiation detriment associated with diagnostic x-rays procedures for both patient and radiation workers, even though the differences between the two remain (Le Heron, 1992).

It is stressed that there will be uncertainties in the risk values calculated from the dose measurements, whatever the index used. However, there is also great uncertainty associated with radiation risk estimates and therefore the values calculated will be adequate (Le Heron, 1992). The direct use of the dose-area product measurement has merit in regulating radiation and maintaining doses at as low a level as possible. Reference dose levels for x-ray examinations have been set in the UK and the monitoring process is by means of TLDs or DAP-meters (Shrimpton *et al*, 1993). The dose-area product and some of the other dose indexes will be discussed in more detail.

3.1.1 Entrance surface dose

Entrance surface dose can be defined as the absorbed dose to air at the centre of the beam, including backscattered radiation (Hart, Jones *et al*, 1994). The exposure to the skin of the patient during standard radiographic examination or fluoroscopy can be measured directly or estimated by a calculation using the exposure factors used and the equipment specifications. Maree used the method of calculating skin dose from the factors recorded on a questionnaire during the diagnostic radiology procedures of relevance to GSD (Maree, 1995). Suitable methods for measuring the entrance surface dose are with TLDs or by use of a DAP-meter. Both these methods were discussed in chapter 2 on Radiation Dosimetry.

3.1.2 Organ dose

In some cases the radiation dose received by a specific organ is important. These can usually not be measured directly and must be estimated. Consideration of the genetic effect of radiation requires an estimation of the dose to the gonads. Bushong, in 1991, gave the average gonad doses resulting from various radiographic examinations. The two relevant to this study are the abdomen and pelvis.

Table 3.1: *Average gonad doses resulting from radiographic examinations of the Abdomen and Pelvis* (Bushong, 1991)

X-ray Examination	Gonad dose to Male	Gonad dose to Female
Abdomen	1.0 mGy	2.0 mGy
Pelvis	3.0 mGy	1.5 mGy

3.1.3 Dose-area product

Dose-area product can be defined as the absorbed dose to air averaged over the area of the x-ray beam in a plane perpendicular to the beam axis, multiplied by the area of the beam in the same plane. Backscattered radiation is not included (Hart, Jones *et al* 1994). The use of a DAP-meter is well suited to measuring the dose to the patient for a complete examination involving screening and radiographs. This dose quantity is easily measured and is considered by some to be sufficient for checking and comparing the effectiveness of modifications to technique or equipment that are introduced to reduce patient dose (Shrimpton *et al*, 1993). The

DAP-meter is an aid to patient care as it allows for the minimising of patient dose while not compromising the quality of the x-ray image. During fluoroscopy, the kVp and mA change as the density of the area being imaged, changes. The size and position of the beam also changes. The DAP-meter gives an indication of patient dose via the unit Dose Area Product (NE-Technology, 1996). As more information becomes available and more studies are completed it may be possible to use the direct reading of dose-area product for patient protection purposes. This is a simple system of monitoring dose that requires no further calculations and it can be easily done within the confines of a busy x-ray department.

The NRPB suggests that DAP-meters can be conveniently fitted to the diaphragm housing of x-ray units to monitor the radiation dose to the patient which can provide a useful guide to the performance of the equipment and the radiologist/radiographer in keeping the patient dose to a minimum. In order to use the DAP-meter readings meaningfully extensive measurements are necessary. The NRPB national survey was extensive and the results for the Ba E are shown below.

Table 3.2: *Dose-area product readings for the Barium Enema x-ray examination* (Shrimpton *et al*, 1986)

Dose-area product (Gy cm^2) for the Barium Enema					
Equipment	Minimum	First Quartile	Median	Third Quartile	Maximum
Conventional	6.18	25.73	40.5	60.93	271.76

3.1.4 Effective dose

Effective dose is based on the principle that the risk of a stochastic effect per unit effective dose equivalent should be equal whether the whole body is uniformly irradiated or whether the radiation dose is non-uniformly distributed (ICRP 26). The exact calculation of the effective dose received by a patient needs a knowledge of the dose to 22 organs of the body. This is complex for diagnostic radiology and unlikely to be available on a routine basis although it is considered by some that it may become the preferred risk-related dose quantity for radiological protection and diagnostic radiology (Hart and Wall, 1994).

Effective dose is the weighted sum of the equivalent doses to each of the tissues of the body exposed. In the case of uniform total-body exposure this quantity is simple to calculate. It is more complicated when parts of the body are exposed such as is the case in diagnostic radiology. This index is considered by some to be the most suitable quantity for relating

radiation exposure to somatic risk but is not that suitable for relating radiation exposure to genetic risk (Hall, 1994). Le Heron presented comprehensive tables of conversion coefficients for estimating effective dose from dose-area product. This was simplified into conversion coefficients for common x-ray projections in a further table. On condition that the x-ray exposure is made using a peak kilovoltage within the range specified, then the estimated effective dose will be within 30% of the estimate that would be obtained using the appropriate values and the more complex calculation (Le Heron, 1992).

In a similar attempt to overcome the daunting task of calculating the effective dose there was a conversion factor proposed by Hart and Wall. The DAP-meter measurement multiplied by a factor of 0.28 or simply rounded to 0.3 mSv/Gy cm^2 can be used in order to estimate the effective dose for a Ba E as an indication of radiation risk. This estimate of effective dose is approximate and there will be a potential error of about 14%. Since there are many more variations in technique when considering complete examinations rather than single radiographs, there is a larger potential error, but the error will rarely be more than 25% (Hart and Wall, 1994). However some motivate an even simpler method of estimating risk to the patient. The entrance surface dose is considered easy to estimate or measure for standard radiography while the patient dose from x-ray examinations involving multiple exposures and screening are, in recent years, more commonly conducted with the use of a DAP-meter (Le Heron, 1992). This means that while effective dose is not an index that will be calculated in this study it is presented to demonstrate the versatility of DAP-meter measurements for calculating radiation risk.

3.1.5 Genetically-significant dose (GSD)

The genetically-significant-dose (GSD) is a genetic dose index of the presumed genetic impact of radiation exposure on the total population and can be determined for diagnostic radiology (Maree, 1995). This means it is a prime index of risk to the descendants of a population from diagnostic radiology.

Bushong explains that the population is exposed to ionising radiation from many sources. The major source is that of natural background radiation over which we have no control. However the source of man-made radiation, over which we do have control, and which is of most significance in the majority of countries, is the dose received due to medical applications. The most important medical exposure is the dose received by patients from medical radiographic procedures. A measure of patient dose as a means of assessing the extent of medical radiation exposure on the population is the GSD (Bushong, 1991). It is known that more than 80% of the GSD is due to less than 15% of all types of radiology examinations to both sexes in all age groups (Moores *et al*, 1984).

The GSD is a measure of the effect of radiation dose on the generations of the future. The effect on the future generations is due to the genetic effects of radiation, which are the radiation induced mutations on the reproductive cells of this generation.

The GSD is obtained by multiplying the estimated gonad doses of the individuals with a weighting factor, namely the child expectancy of the individual. GSD results can vary by a factor of almost 10 for different countries (Maree, 1995).

Definition of GSD:

The gonad dose which, if received by every member of the population, would be expected to produce the same total genetic injury to the population as do the sum of the individual doses actually received by the various individuals. This can be stated as the annual per caput gonadal dose that results in the same genetic detriment as the gonadal doses actually received by the fraction of the population exposed to diagnostic x-rays in the year in question (Maree, 1995). The GSD indicates nothing about possible or probable genetic effects. It is merely an attempt at estimating the dose received by the population gene pool (Bushong, 1991).

Analysis of the GSD from diagnostic radiology can be used to estimate possible detriment from a specific practice (Hall, 1994).

In the report by Maree the benefits of a survey on GSD for South Africa are discussed and the statement is made that it facilitates:

1. Comparison of the contribution of various examinations to the GSD with those of other countries.

2. Follow-up studies to determine an increase or decrease in the contributions of the various examinations.

3. The identification of examinations where a special hereditary health risk exists.

The GSD due to radiation exposure depends on the absorbed dose to the ovaries or testes and on the age of the person, as this determines the probability of that person bearing children in subsequent years. As women over the age of 50 years have little chance of having children, x-rays of them contribute very little to the GSD of the population. The exposure of the gonads of children results in the maximum contribution to the GSD of the population as they have the maximum potential for child-bearing. (Maree, 1995).

Wall reported that the GSD to the population of Great Britain from diagnostic radiology was considered as very important. The fact that there is no direct benefit to the descendants of patients undergoing medical examinations was a significant motivation for a close watch on the genetic risk. As a relatively large proportion of the fertile population is subjected to radiological examinations each year it was made a priority (Wall *et al*, 1980).

In the 1950s a committee, under the chairmanship of Lord Adrian, conducted an extensive survey of dose measurement for x-ray examinations in 130 hospitals in Great Britain. Wall *et al* conducted a more cost effective survey 20 years later and some comparisons were drawn on gonad dose as a consequence of various examinations. Some examinations show a decrease in the dose delivered to the gonads while others demonstrated no significant change in the mean gonadal dose since the time of the Adrian survey and yet others show there has been an increase. Of particular note was that the gonad doses from Ba Es stand out as being considerably higher. This increase in dose is the result of the increase in the number of spot films taken today during this examination (Wall *et al*, 1980).

The survey, conducted by Wall *et al*, in Great Britain enabled an estimate to be made of the annual GSD to the population from the current level of diagnostic x-ray examinations (Wall *et al*, 1984).

Genetic risk is expressed by the quantity, GSD. The unit of GSD is the sievert (Sv). The equivalent dose to the gonads is weighted for the age and sex distribution in those members of the exposed population expected to have offspring. As such it is an index which indicates the presumed genetic impact of radiation on the whole population by an attempt to average the genetic effects over the whole population. The GSD for the total population is the dose that, if received by every member of the population, might be expected to result in the same total genetic injury to the population as do the actual gonadal doses received by the various persons exposed (Hall, 1994).

3.1.6 Collective effective dose

The quantity of collective effective dose is considered by Hall to be a relevant quantity when evaluating the effect of diagnostic radiology on the population as a whole. This dose quantity is the sum of the product of the effective dose and the number of persons exposed. Estimates of collective effective dose are fraught with difficulties and the result is far from precise. It is noted, however, that for the United States of America in 1980 the Ba E made the largest contribution to the collective effective dose. The Ba E contributed an amount of 19,900 person-Sv to the total of 92,000 person-Sv (Hall, 1994).

3.2 PATIENT PROTECTION

The system of dose limitation recommended by the ICRP is founded on three basic tenets stated in its Publication 26 and reiterated in its Publication 60:

1. *Justification* - No practice shall be adopted unless its introduction produces a net positive benefit.

2. *Optimisation* - All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account.

3. *Dose Limitation* - The dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances.

In recent years there have been attempts by some state bodies to restrict the radiation exposure to patients during routine radiographic examinations while at the same time recognising that an inadequate examination/image caused by too low a dose can also be harmful to the patient (Bushong, 1991).

Radiation protection of the patient involves both medical and technical decisions. The medical decisions include the consideration of whether or not an examination is required, which examination would be the most appropriate and any possible contraindications to the patient having the study. The technical decisions relate to the choice of appropriate equipment and apparatus and to technique. It is noted that the reduction of the radiation dose by changes to the equipment will result in a more consistent reduction while reduction due to radiological technique need constant effort to maintain the benefit (NCRP, 1989). One further aspect of radiation protection is the necessity of following a strict administrative procedure and training. In the long term changes to the equipment used will impact on dose to the patient. However on a day-today basis, once the decision is made to do a Ba E, the factors affecting dose to the patient will be the radiologist and radiographer technique which includes the screening time, the number of exposures, the exposure factors selected and the beam collimation.

3.2.1 Equipment and Apparatus design

There are many radiation-protection features and accessories on modern x-ray equipment. Some are characteristic of radiographic and some of fluoroscopic units. The individually mentioned items below are those relevant to the limiting of patient dose during a Ba E examination only and do not incorporate all radiation protection features.

3.2.1.1 Filtration

Bushong states that a minimum of 2.5 mm Al equivalent total filtration is required on all fluoroscopy tubes and for radiographic tubes which operate above 70 kVp. The filtration reduces the amount of low energy radiation

reaching the patient. This soft radiation does not contribute to the x-ray image and is only responsible for increasing the dose to the patient. As a general principle, the higher the total filtration the lower the patient dose (Bushong, 1991). The three units used in this study fall in line with the South African and international standards for radiology screening equipment and were all more than the minimum recommended 2.5 mm Al equivalent total filtration.

3.2.1.2 Collimation

The x-ray beam should always be collimated to the region of interest as the dose increases with field size. It is recommended that light-localised, variable-aperture, rectangular collimators should be used. The x-ray beam and light beam must coincide to within a permitted error margin of 2% of the source-to-image-receptor-distance (SID) (Bushong, 1997). Collimating the beam reduces the volume of tissue irradiated and also the dose received from scattered radiation. The importance of collimation, for patient protection, must never be underestimated (Bushong, 1991). It is recommended that for fluoroscopy equipment automatic collimation should be a feature of the equipment. This is so that with any film size in use and at all standard SID the collimator shutters automatically provide an x-ray beam equal to the dimensions of the image receptor. When the unit is screening there should be an unexposed border visible on the television monitor at all times which is an indication that the area being exposed is limited to the viewing area (Bushong, 1997).

3.2.1.3 Image receptors

The first medical radiographic image receptors were a glass plate with a silver-halide coating. Subsequently film was used. Pizzutiello *et al* goes on to say that only about 1% or 2% of the x-ray fluence in the primary beam emerging from a patient is absorbed by a sheet of x-ray film (98% or more passes directly through the film and does not contribute to the image). It was soon realised that there would be an advantage if more of the wasted x-ray energy could be used to produce the image. The intensifying screen was designed to optimise absorption of the radiation by converting absorbed x-ray energy into visible light which would be more readily absorbed by the film than the more energetic x-ray photons. The advent of fluorescent intensifying screens (screens) which act as an image amplifier and their use with x-ray film which is highly sensitive to the visible light photons, significantly reduced the absorbed dose to the patient while still maintaining the image quality. The intensification factor is the radiation exposure required without screens divided by the exposure required with screens to provide the same film blackening effect. This factor is dependent on the screen, the film and the exposure factors. One method of classifying screens is to put them into categories according to their relative light output or speed. In radiography the speed of an image

receptor is inversely related to the radiation exposure required to produce a certain amount of film blackening. Therefore a fast screen (high speed) requires less x-ray exposure than a slow screen (low speed) to provide a given image density. Rare-earth screen-film combinations, in use today, reduce the patient dose considerably without loss of diagnostic quality (Pizzutiello *et al*, 1993).

Meaningful measurement of screen speed is complicated and in practice the measurement of the response of the system (screen-film combination, plus processing) is more useful. The investigation of the centres in this study shows that 200-speed, rare-earth systems were in use for Ba E at the centre A and C. These are high speed screen systems which though not the fastest available, are standard equipment in an x-ray department today. The majority of the images at centre B, where measurements were taken, were exposures using the storage-phosphor-screen system linked to a digital processor. The screen speed for the cut-film exposures (35 x 35 images only) was unknown and unable to be verified with the manufacturer. The frequency of the use of cut-film for a Ba E during this study was <1 per patient and therefore the screen speed is of relatively little significance to total patient dose at this centre.

The image intensifier tubes, in use today, also have efficient input phosphors that play a role in reducing the dose to the patient (Bushong, 1991). The three units involved in this study had image intensifier tubes with similar characteristics.

3.2.1.4 Source-to-Image-receptor Distance

As the dose to the patient is reduced when the source-to-skin-distance (SSD) is increased it is essential that the maximum realistic distance is maintained at all times. The SSD is related to the source-to-image-receptor-distance (SID) and therefore equipment with a larger SID will result in a lower dose to the patient. This is of importance both for radiography and fluoroscopy. The recommended source-to-skin distance for a undercouch fluoroscopic tube is a minimum of 30 cm and more when possible as the patient dose is very much higher when the tube is close to the table top (Bushong, 1997). There should be a SID indicator which must be accurate to within 2% of the indicated SID (Bushong, 1997).

3.2.1.5 Cumulative timer and Audible warning

Fluoroscopy units should have a built in cumulative timer device and an audible warning system which rings after a pre-set fluoroscopy time has elapsed. This is usually set at 5 minutes for Ba E procedures. This can be reset without cancelling the recording of the total screening time and radiologists must be aware of the serious patient dose implications if the alarm is reset during the examination such that the screening time exceeds

the pre-set time (NRPB, 1990). The elapsed timer does not ensure safe operation but is of value as a training device for physicians learning the techniques of fluoroscopy and for all users as a means for monitoring the passage of exposure time (NCRP-102, 1989). Centres A and C have the audible warning set for 5 minutes and the radiographer re-sets the alarm on the control panel. At Centre B it is set for 4.3 minutes and the radiologist re-sets on the mobile control unit.

3.2.2 Technique

Technique is a critical factor in patient dose and it must also be stressed that repeat images taken due to technique error must be kept to a minimum in order to reduce the patient dose from this unnecessary exposure. The radiographic technique is important for the quality of the image but also plays a very important role in patient dose. The most significant aspects of technique, affecting radiation dose to the patient are:

3.2.2.1 Tube voltage and tube current

A compromise must be sought in order to use the highest kVp possible, so that the dose to the patient is at the lowest possible level, without reducing the image contrast to an unacceptable level (Bushong, 1991). In general the use of a high kVp technique results in a lower dose to the patient. An increase in kV results in a reduction in mAs in order to obtain an acceptable radiograph. This, in turn, means a reduced exposure. This is because the patient dose is linearly related to the mAs, but it is approximately related to $(kVp)^2$ (Bushong, 1997).

$$\text{Dose} \cong \text{Constant} \times (kV_p)^2 \times mAs$$

(Curry *et al*, 1990)

The NCRP recommends that the kVp and mA should be visible to the person doing the fluoroscopy at all times (NCRP-102, 1989). This was not the case for one of the units in this study. The other two units had remote control and if used this allows the user to visualise the exposures set. However the equipment was most frequently controlled from the bed-side in which case the exposure factors were again not visible

3.2.2.2 Filtration

The total filtration of an x-ray beam is an important factor, together with applied potential, in determining the radiation quality. It is expressed in terms of an equivalent thickness of aluminium which, for a specified applied potential, represents the mixture of glass, oil, etc. that is traversed by the x-ray beam (Shrimpton *et al*, 1986). Filtration is also discussed earlier in this chapter under equipment and apparatus design. However, as it is

frequently possible to select further filtration in addition to that inherent to the equipment, it is also a factor in technique.

Units A and B did not allow for simple filtration adjustment while Unit C permitted additional filtration by the turning of a metal plate situated on the diaphragm housing. It was observed that the additional filtration reading was zero for all Ba Es measured such that no additional filtration was in fact selected on this unit.

3.2.2.3 Source -skin-distance (SSD)

The filtration of the beam and the SSD should be as large as is practical. These two parameters and the kilovoltage increase the relative penetrability of the x-ray beam and therefore deliver a lower dose to the patient for a given exposure to the film (NCRP,1989). The three units on which measurements were done allowed for some variation in the SID, except for the undercouch tube on Unit A which was at a fixed SID of 43 cm. An increase in SID gives a relative increase in SSD and therefore this is also a technique factor.

3.2.2.4 Field size

In the NRPB report R105, Wall *et al* (1980), stated that field size is probably the most important factor which causes the variation in gonadal doses. It is essential that the Ba E is carried out with consideration for keeping the field size to the minimum possible at all times during the study.

3.2.2.5 Intensifying screens and other image recording devices

X-ray films, intensifying screens and other image recording devices should be as sensitive as is consistent with the requirements of the examination (NCRP,1989). This is a factor in all radiology procedures including the Ba E.

3.2.2.6 Screening time and Exposure factors

Significant reductions in radiation dose to the patient can be made by the conscious efforts of the radiologist to keep the screening time to a minimum. In a Ba E the barium should be followed intermittently and for short periods as it flows through the colon. In addition fluoroscopy is used for positioning and obtaining spot views. The radiologist should rely on the radiographs to identify any abnormalities and extensive fluoroscopy should not be used for this purpose. During fluoroscopy the beam should be collimated to the smallest that still show the features required. The screening mA and kV should be kept as low as gives an adequate image (NRPB, 1990).

The general principle should be to keep the dose to the patient to a minimum consistent with clinical objectives, but bearing in mind that too low a dose may compromise the examination (NCRP, 1989).

3.2.3 Administration

Administrative control is mentioned in the NRPB document of 1990 as being a factor in the reduction of unnecessary patient dose. This administrative control is a shared responsibility between the requesting medical staff, the radiologist and the radiographer. Any x-ray examination done should influence the management of the patient, with symptoms. A request for the x-ray of a patient without symptoms, to provide baseline information or to satisfy legal, insurance or employment requirements, is more controversial and the routine examination of persons in this category is under question. Another important method for reducing the radiation dose to patients and the GSD is the efficient storage and retrieval of previous x-ray images in order to avoid unnecessary repeat investigations due to previous films not being available (NRPB, 1990).

Administration was not included in this study but it must not be underestimated in its significance to patient dose and ultimately to GSD. A quality assurance programme needs to be in place to govern and control the administration with respect to dose to the patient.

Chapter 4

THE BARIUM ENEMA

The most frequently performed fluoroscopic examinations and those which make the largest contribution to collective effective dose are the barium contrast studies of the stomach, duodenum and colon (Hall, 1994). In fact in the UK it is estimated that 26% of the collective dose from medical x-rays is due to the contribution of barium examinations (meals and enemas) (Martin *et al*, 1994). The latter investigation, the Ba E, is the radiological examination of choice if disease of the large bowel is suspected (Sutton, 1995) and as such is a relatively frequent procedure in any x-ray department. The Ba E examination allows for the physical examination of the entire colon and rectum. The examination is minimally invasive and the patient is able to tolerate it without sedation. When performed with care this examination will provide satisfactory sensitivity and specificity for the detection of carcinoma and for the detection of adenomatous polyps of more than a few millimeter in size (Gelfand, 1996).

The Ba E is a complex investigation which, though not a frequently performed study, is considered to be a high dose procedure of significance when considering radiation dose to the patient or to the population (Shrimpton *et al*, 1986).

4.1 The study of Maree

The results of the work by Maree high-lighted the significance of the Ba E, when calculating the GSD for the South African population, and this examination was selected to investigate in more detail for this study. In the research of Maree statistical information on radiology examinations and total number of patients x-rayed was obtained from a total of 292 institutions in South Africa. A model was determined in order to draw the best representative sample of the population and this was done in a unique way in that the Dollar Unit of Sampling was used. It is a sampling technique whereby the larger the volume of x-ray procedures of the institution the greater the likelihood to be included into the final sample. This resulted in 27 (9%) of the possible 292 institutions being included in the sample and this meant that 25.8% of all examinations performed during a specific week were used for the calculation of the GSD (Maree, 1995).

Data was gained for 96 radiology examinations. Of these, 30 of the radiology examinations were considered to make an appreciable contribution to gonad dose. These 30 examinations were used, by Maree, in the calculation of the GSD with an error of 37%. The Ba E x-ray examination contributes significantly to the GSD of White females (Figure 1.3) and was selected as the single radiology examination in this study to investigate by means of dose measurement. This decision was made for the following reasons:

1. There is both screening and plain radiography involved in this radiology examination.

2. This procedure has been identified as a significant contributor to gonad dose (Maree, 1995). The study of Wall *et al* in 1980, also demonstrated that the barium enema was the examination, in females, which resulted in the highest mean gonadal dose.

3. Dose measurements for this examination are able to be compared to both the calculated and measured results of other studies.

4. It was anticipated that the difference in the dose measured between males and females would be significant and give possible substantiation to the results of Maree.

5. The doses measured were not expected to indicate a difference in the 4 female race groups. This would remove one unknown factor and limit the results of Maree to factors other than the dose received by individual patients. Further than this it would allow the aspect of race to be ignored in dose measurement studies which is appropriate for health management in South Africa today.

Prior to conducting measurements, all Ba E cases used in the GSD calculation by Maree were isolated . The total Ba E examinations assessed in his research was 217. These included 147 Ba Es conducted in private institutions and 70 in state institutions. Any comparison of GSD will be done using the data calculated by Maree and will therefore include all the patients in that study. Additional comparisons on equipment and technique will be done and for the purpose of these comparisons some of the patient data will be excluded. The following data was excluded prior to these comparisons being made:

Incomplete examinations or data not given:

1 patient was excluded as no exposures were either done or recorded.
39 patients were excluded due to there being no screening time recorded.
These given facts are considered unlikely to reflect the situation correctly and have been taken as an omission of data as it is usual for a Ba E examination to be conducted with screening first and standard radiography exposures to follow. On both accounts it was considered justifiable to exclude these cases from the data for the purpose of comparing technique.

Examinations on children:

All examinations conducted on children were excluded.
7 in total were excluded, 1 of which would have been excluded under the criteria of no screening time as well.
The youngest patient included in the age group > 15 years was 19 years.

The study by Maree divides the results into four age categories for data on; average technique values for diagnostic examinations, patient thickness, skin entrance and gonad doses for diagnostic x-ray examinations. The Ba E has data for two age groups only. These are the groups: (>5-15) and (>15). The data for the latter group of Maree will be used for a comparison with this study which includes only adult patients >15 years and no children.

The total number of patients assessed was therefore 170. This included 115 from private institutions and 55 from state institutions. The results of this analysis are recorded for State Hospitals in Table 7.1, for Private Centres in Table 7.2 and the Combined results in Table 7.3. The results will be considered in Chapter 7, Results and Chapter 8, Discussion.

4.2 Technique

There are two radiological methods used for the examination of the large intestine by means of contrast enemas. These are the single-contrast method, in which the colon is examined with a barium sulphate suspension only and the double-contrast method in which the colon is examined using barium sulphate suspension and air (Ballinger, 1986).

A Ba E x-ray examination includes screening and hard copy or digital images. The procedure given below is a standard protocol. However, it must be stressed that the procedure will vary from centre to centre and even from one radiologist to another, within the same centre such that recording a standard is merely a starting point from which to compare the centres involved in this study.

According to Ballinger (1986) the Ba E x-ray examination will always involve:

1. Bowel preparation.

2. Barium sulphate suspension as the contrast medium, introduced via a rectal catheter, under screening control.

3. Visualisation of the rectum and colon by screening. This can vary from 3-12 minutes or more.

4. Positioning of patient to facilitate the flow of the barium to the splenic flexure or transverse colon.

5. Excess barium run out and in most cases the addition of air to produce double contrast.

6. Images taken using the spot-film technique undercouch or overcouch and additional images using the overcouch x-ray tube.

The sections of the colon that need to be visualised in a Ba E are (Sutton, 1995):

1. Rectum
2. Sigmoid colon
3. Transverse colon
4. Splenic flexure
5. Hepatic flexure
6. Caecum
7. Ascending colon
8. Descending colon

A typical routine for a Ba E examination at Groote Schuur Hospital Radiology Department would involve the following projections or variations on this to suit the needs of a particular patient and radiologist:

Projections	**Cassette size**	**Exposure Factors**
Spot films		
Lateral Rectum	18 x 24	117kV 50mAs
AP Oblique Sigmoid Colon	24 x 30	109kV 20mAs
PA Oblique Sigmoid Colon	24 x 30	109kV 25mAs
Erect AP Transverse Colon	35 x 35	109kV 25mAs
Erect AP Oblique Splenic Flexure	24 x 30	109kV 40mAs
Erect AP Oblique Hepatic Flexure	24 x 30	109kV 40mAs
AP Oblique Caecum	24 x 30 (split 2)	109kV 25mAs
Non-routine spot views		
AP Rectum	18x24	109kV 25mAs
AP Ascending Colon	24 x 30	109kV 25mAs
AP Descending Colon	35 x 35	109kV 25 mAs
Standard radiography		
Supine Abdomen (include symphysis pubis)	35 x 43	109kV 20mAs
Prone Abdomen (30° Cranio-caudal)	35 x 35	109kV 25mAs
Prone Abdomen	35 x 43	109kV 15mAs

The three centres involved in this study differed from the above protocol in the following ways:

Centre A

1. A control AP abdomen view on a 35 cm x 43 cm film was routinely done prior to commencing the Ba E.

2. Both lateral decubitus views were done routinely in addition to the three standard radiography views at the end of the study.

3. The number of exposures that were taken on the patients during this study has a mean value of 15.0.

Centre B

1. A control AP abdomen view on a 35 cm x 43 cm phosphor screen was routinely done by two of the radiologists prior to commencing the Ba E. This was not the case for the other radiologist who did not request a control view.

2. The number of exposures that were taken on the patients during this study has a mean value of 18.0.

Centre C

1. The prone abdomen 30° cranio-caudal was done during the screening part of the procedure as a spot-film by one radiologist. The others followed the protocol of this view as a standard radiography exposure at the end of the procedure.

2. The number of exposures that were taken on the patients during this study has a mean value of 12.7.

4.3 Radiation dose

The gonadal doses are inevitably high for the Ba E examination because the ovaries or testes are within or very close to the area of interest (Hall, 1994). The reduction of dose is therefore connected to equipment and technique factors which will be considered for this specific examination.

4.3.1 Technique and dose

The single-contrast Ba E was routinely used for many years, but this has largely been superseded by a technique using air distension of the barium-coated mucosa which increased the diagnostic accuracy of the examination

(Sutton, 1995). Barium sulphate double contrast examinations are complex and they make up 26% of the collective, effective dose in the UK (Burniston, 1993). This double contrast technique, introduced in the late 1970s, doubled the number of radiographs taken and more than doubled the gonadal doses (Wall *et al*, 1980). The opinion of Wall *et al*, that the dose is usually higher from double contrast studies than single contrast studies, is generally accepted. However it has also been stated that the double contrast study gives less radiation dose (Ward, 1995). At the institutions where measurements were conducted for this study, the use of double contrast is considered to be the standard technique and very few patients have a Ba E using the single contrast method. This makes a comparison of dose for the two techniques difficult. However the dose measurements done during this study did record the contrast method and the impact of this on dose will be discussed.

It is often possible to reduce excessively high doses down to more acceptable levels by simple changes in technique such as increasing the x-ray tube voltage or employing a faster film-screen combination (Wall, 1996). The study by Hart and Wall reinforces that the dose in fluoroscopy can be minimised by using as low mA and kV factors as possible and by being conscious of collimation and short intermittent exposures (Hart and Wall, 1994).

4.3.2 Equipment and dose

Equipment is available for digital imaging with post-processing, which can alter the radiographic image quite markedly (Ward, 1995). Digital units are being used more frequently for barium studies. The digital radiography system offers the possibility of imaging at a range of dose levels which provide an image that may be processed and displayed in a number of ways. These digitally-enhanced images can theoretically be obtained at a much lower patient dose than conventional film-screen systems and a marketing feature of the digital unit is the advantage of a possible dose reduction. This claim of dose reduction has not been confirmed unequivocally. There is a study with a large number of patients which indicated that the dose from a digital unit is approximately half that of the dose from a non-digital unit during barium studies (Broadhead *et al*, 1995). However there is another study which demonstrates that the fluoroscopy portion of the study often shows an increased dose when compared to conventional equipment which essentially negated any dose decrease due to less spot images being taken (Hart *et al*, 1995). This study includes measurement on a digital unit and conclusions will be drawn regarding the dose received on conventional versus digital equipment.

Chapter 5

DATA ACQUISITION

The discussion under Chapter 2 (Radiation Dosimetry) introduces the DAP-meter as a suitable ionisation chamber for the measurement of dose received by the patient during a Ba E x-ray examination. This ionisation chamber was selected for this study and data was collected on a record sheet designed specifically for this study (Appendix A1).

5.1 Record sheet

The information required on the record sheet was:

5.1.1 General information

This information included age, mass, gender and race. Age and gender were required for the calculation of GSD. Race was recorded in the research of Maree because in South Africa he found it to be a factor in child expectancy which is a factor in the GSD. There is a difference in the total fertility numbers (i.e. the average number of children born to a woman during her fertile years of 15 to 49 years of age). Maree used the fertility numbers supplied by the Population Development Program (Department of Health) and adapted them in order to obtain the child expectancy of the different race groups in South Africa (Chief Directorate, 1994). In order to draw conclusions from this study and compare them to the results of the work done by Maree the race again had to be recorded. The mass was also included as it is an important factor in dose to the patient.

5.1.2 Technical information

This information included some data common to the unit and some data specific to each patient.

5.1.2.1 Data common to the unit:

The Ba E examination, institution (coded A, B, and C), date, channel on the DAP-meter (channel one was used for all measurements done in this study), Unit (coded P, T and S), filtration (total filtration of the unit), source-image-distance (SID) and table top to image-receptor distance (in order to calculate SSD).

5.1.2.2 Patient specific data

The screening time in minutes and the screening exposure factors (kV and mA), the radiography technique factors, namely the view (AP, PA, Lateral), the image-receptor size, tube voltage (kV), workload (mAs), total

exposures, DAP-meter reading of time in seconds and dose in Gy cm^2. The comments column allowed for the recording of the contrast medium used (single or double), the patient separation in the AP, PA and Lateral position (used to calculate the SSD), the radiologist (coded for confidentiality), tube current (mA) was recorded where possible and repeat exposures (with the reason for the repeat being necessary).

5.2 Average technique factors

The computer programme that was used by Maree to calculate gonad doses, makes provision only for the AP, PA and Lateral. In order to compare the results of this study with those of Maree it was necessary to conform to the same limitations of view and therefore to replace AP Oblique with AP, PA Oblique with PA and Lateral Oblique with Lateral. Mean exposure factors for these three projections were calculated from precisely recorded data for each patient.

5.3 Patient sample

The objective of the measurements is to obtain an indication of the typical dose that is delivered to an average adult patient during a Ba E x-ray examination. A sample of about ten patients is deemed adequate to measure the typical dose for a diagnostic radiology procedure (Hart *et al*, 1995).

Information for each patient participating in the survey was recorded but identified only by a serial number. The personal data recorded was age, sex, race and weight, with the latter quantity being an approximate value supplied by the patient or estimated.

Direct dose measurements on patients having the examination provide the best indication of the actual dose received. Patients vary physically and this means that the thickness and density of the part of the body being examined will influence the dose. In order for the dose measurements to be representative of routine practice and to be able to compare them with dose measurements from another institution or other norms, careful selection of the measurement sample is required. The average value of the doses measured on a representative sample of at least ten patients per facility is considered to provide a good indication of typical clinical practice (IPSM,1992). Male and female adult patients were selected and 46 patients were included in this group.

The patients were selected from two tertiary state institutions and one private practice in the Western Cape. The reasons for selecting these institutions were:

1. In order to draw conclusions on this study as related to the study by Maree it was essential to do measurements at more than one institution in order to establish a mean dose on barium enema examinations representative of a cross section of patients, techniques, equipment and operators.

2. Measurements taken at these three institutions would include patients from all sex-gender-race groups included in the study by Maree as well as patients having a representative sample of age and mass.

3. The three institutions permitted measurement on three distinctly varied equipment types which are discussed in detail later in this chapter. They also used different techniques and provided a pool of radiologists. In addition to creating a representative sample, this also allowed for a comparison of dose as pertaining to the equipment and the technique used.

4. Although the measurements caused minimal inconvenience it was essential that the centres involved were co-operative and permitted free access for the purpose of the measurements. These three centres demonstrated an openness to the research being done and were extremely obliging for the full duration of the measurements.

5. The objective of using the measurements in order to establish a regional reference dose for the Western Cape for the barium enema examination would be met by involving these three institutions in this study.

6. The high number of barium enema examinations done at the one centre involved enabled a relatively large number of patient measurements to be done. This compensated for the fact that the numbers of these procedures was low at the one state institution and even lower at the private practice. However the institutions selected needed to do a sufficient number of barium enemas to allow for achieving the minimum number of ten patient measurements at each centre within the time period of six months.

Children were not included and the patients accepted would be 15 years and upwards. In the research of Maree four main age groups were distinguished in order to calculate the gonad doses, namely 0-0.5 years; >0.5-5 years; >5-15 years and >15 years. The Ba E examination had data for the latter two age groups only and in this study there were in fact no patients younger than 26 years of age encountered. Doses measured in this study could be compared to the dose calculations of the age group >15 years from Maree's work. Doses delivered during paediatric radiology depend critically on the size, and therefore the age of the child. There are no well-established reference doses for paediatric examinations at present (IPSM, 1992). Paediatric patients were therefore not measured for this study. However the importance of measurements on children is noted and the methods of measurement could be as for this study but specified for a well-defined size or age range.

Adult patients of any mass were measured and the comparison of the present study with the results of Maree would include all the patients. In order to calculate a

reference dose it is recommended by Hart that measurements are conducted on average sized adults within the weight range of 50-90kg. Selecting patients so that the mean weight of the sample lies within 5 kg of 70 kg has been shown to be representative for the average value of doses to be a good indication of the typical dose to an average patient (Hart *et al*, 1991). The mean values for mass for the Ba E patients in Maree's study and the present study were also within 5 kg of 70 kg which indicates that the mean mass of 70 kg is appropriate for the South African population.

Incomplete examinations were excluded. Examinations which are prematurely terminated, for whatever reason, should not be included in the sample of measurements from which the average dose is calculated (IPSM,1992).

5.4 DAP-meter Measurements

The measurements were done, at the three institutions, using a unit where the Ba E x-ray examination is routinely done. The measurements involved the use of the same DAP-meter and data-collector at all institutions. The data was recorded for all patients. Appendix A2 is an example of a completed data sheet used in this study for the recording of information on each patient having a Ba E. Details of the DAP-meter and the x-ray units will follow.

An effort was made to obtain full information about the type of x-ray equipment installed in the institutions involved, although this was not always possible. Also a record was made of the radiographic technique used in each case which included the sequences used for the Ba E examination and the exposure factors.

5.4.1 Database

The software package used was Microsoft ® Windows® 95 Excel version 7.0 which was used and run on a Pentium personal computer.

5.4.2 PTW - Unidos Dosemeter

The dosemeter used for calibrating the DAP-meter was a PTW Universal Dosemeter with a 0,6 cc Ionisation Chamber and Reference Source. The dosemeter was manufactured by PTW- Freiburg, with model number Unidos-10002, Ionisation chamber type - W 30001 and Sr-90 reference source type number - 48002. This instrument is a secondary standard dosemeter calibrated by the CSIR. The factor of 1,049 R/Gy supplied by the CSIR for the HVL's between 2 and 3 mm Al was used in this study.

5.4.3 DAP-Meter

The dose area product meter used for the current measurements (NE Technology Limited, Dose Area Product Meter type 2640A) measures the dose for the complete procedure, including repeat radiographs, in order to

reflect the actual dose required to obtain a diagnostic result. Transmission ion chambers were used to measure the output of diagnostic x-ray units during the examination of patients. This two-channel instrument allows measurement of the dose area product for both over and under couch tubes. The two sizes of ion chamber that are available are the type 2641A (large) and type 2642A (small). The type 2642A (small) chamber was used in all three centres where measurements were recorded for this study. The DAP-meter was calibrated by the manufacturer. The chambers are of vented type, which allows for the compensation of temperature and pressure variations by transducers mounted in the 2640A electronics housing. The transducer readings are applied automatically in the software for corrected DAP-meter readings. Compensations for temperature and pressure were accepted as correct and not amended or deselected during this study as the DAP-meter was in the x-ray room at all times.

In the case of Unit A there were two tubes and in order to record the dose for the complete examination the transmission chamber was moved between the two tubes during the procedure. The small chamber was fitted to the light beam diaphragm housing of the overhead tube for the control film which was routinely taken at this centre. The reading was recorded and the chamber re-set then the same chamber was moved to the diaphragm housing of the undercouch tube. The reading from this tube included fluoroscopy and radiographic exposures and the total reading was multiplied by a correction factor obtained by calibration of this unit. The chamber was relocated again in order to record the doses from the images taken with the overhead tube at the end of the study. This in fact involved placing it on the diaphragm housing for one exposure and then taping it to the wedge filter, which was placed in the light beam diaphragm, for the two decubitus views. The reading was taken each time before moving the chamber and the control-display unit was reset in order to avoid any errors due to movement of the sensitive equipment.

The moving of the chamber caused little disruption to the patient or the team involved but it certainly required their co-operation. Also of note is that the wires were not easily kept out of the way when the chamber was on the undercouch tube and this had to be monitored at all times. Relocating the chamber and keeping a watch on the wires would be an impossible task to expect the radiographers to do in addition to their other roles during a Ba E procedure and that it can only be considered if there is a person dedicated to taking the measurements. This makes it unlikely that regular readings can be taken on such equipment even with the use of two chambers unless a DAP meter is permanently fitted to the equipment.

5.4.4 Calibration of the DAP-meter for use on the x-ray equipment:

The dose-area product reading will not be a true indication of the surface dose to the patient unless the chamber is calibrated against the particular unit in use. The readings of the Ba Es carried out using an overhead tube only did not vary significantly from the calibrated readings of the manufacturer and no correction factor was therefore used for the readings taken on Unit B and C. The radiographs taken on the overhead tube of Unit A also required no applied correction factor. However the readings for the portion of the study done using the undercouch tube on Unit A were calibrated and a correction factor of 0.920 was applied to these readings (Table 5.1). The use of this equipment results in the situation that there is attenuation of the x-ray beam by the couch which is positioned between the chamber and the patient. In this case the attenuation was not great and the correction factor applied made only a small difference to the readings.

Procedure:

Calibration was performed using two x-ray fields of different area as given in Table 5.1. The precise setting of field size proved to be impossible when calibrating the undercouch tube, however one large and one small field size were used. A large area (16.9 x 18.2 = 307.58 cm^2) and a small area (5.5 x 7.1 = 39.05 cm^2) were chosen in order to check whether this made a difference to the calibration factor obtained. A standard film and screen-cassette was used. The cassette was positioned on a perspex plate with a 20 cm x 20 cm cut-out (Figure 5.1). The perspex plate was custom made for this study in order to ensure that the film was kept at right angles to the x-ray beam across the area of the field. The plate stayed in place for the measurements with the secondary standard ionisation chamber and ensured that the centre of this chamber would be in the same plane and at the same distance from the tube as the centre of the cassette.

The perspex plate was positioned directly onto the couch and the cassette was placed directly thereon (Figure 5.2). The diagrammatic sketch shows the positioning of the perspex plate, cassette and DAP-meter transmission chamber in relation to an overhead and undercouch x-ray tube.

The beam area was determined by measuring the area bounded by the line on the exposed radiographic film where the optical density falls to 50 % of its maximum value, using a densitometer and a ruler.

The PTW secondary ionisation chamber was corrected for temperature (the mean of the ambient temperature taken at the beginning and the end of the procedure) and pressure. The initial ^{90}Sr check showed a deviation of + 0.22 %.

The calibration measurements for the DAP-meter compared to the secondary standard ionisation chamber were carried out at three exposure settings typical of those used on that unit for Ba Es. The exposures for Unit A and the results of the mean of two readings for each exposure are shown in Table 5.1. A formula was applied to obtain the correction factor (F_1) for each exposure and field size and the mean of these was used as the correction factor (F_2). The differences are small enough to include the values for the large and the small areas in a single mean value (F_2).

The formula applied was:

$$D \times 10^{-3} \times A \times f \times Q = X$$

$$F_1 = \frac{X}{DAP}$$

D : Mean of 2 readings on secondary standard dosemeter in mGy
A : Area as measured from the exposed x-ray film
f : R/Gy conversion (0.870)
Q : Calibration factor for HVL of 2 - 3 mm Al (1.049)
DAP : Mean of 2 readings on DAP-meter in Gy cm^2
F_1 : Correction factor for each exposure

Table 5.1: *Calibration of the undercouch tube of Unit A*

	Exposure Factors		Secondary standard	DAP	Correction
	kV	mAs	mGy	Gy cm^2	Factor (F_1)
A_1	120	75	40.830	11.830	0.969
	80	50	12.270	3.776	0.911
	60	25	3.240	0.997	0.931
A_2	120	75	36.180	1.373	0.948
	80	50	10.785	0.440	0.873
	60	25	2.820	0.113	0.894
F_2					0.920

A_1: Large beam area (16.9 x 18.2 = 307.58 cm^2)
A_2: Small beam area (5.5 x 7.1 = 39.05 cm^2)
F_2: Mean Correction factor

Figure 5.1: *Diagrammatic sketch of perspex plate*

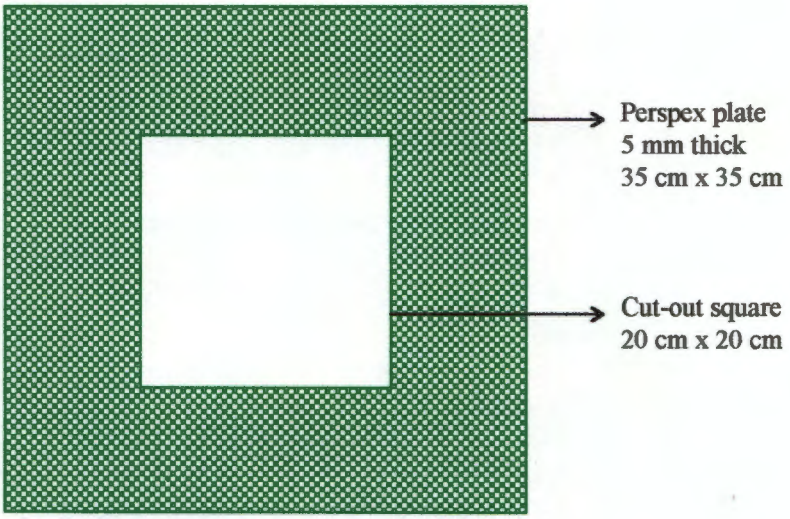
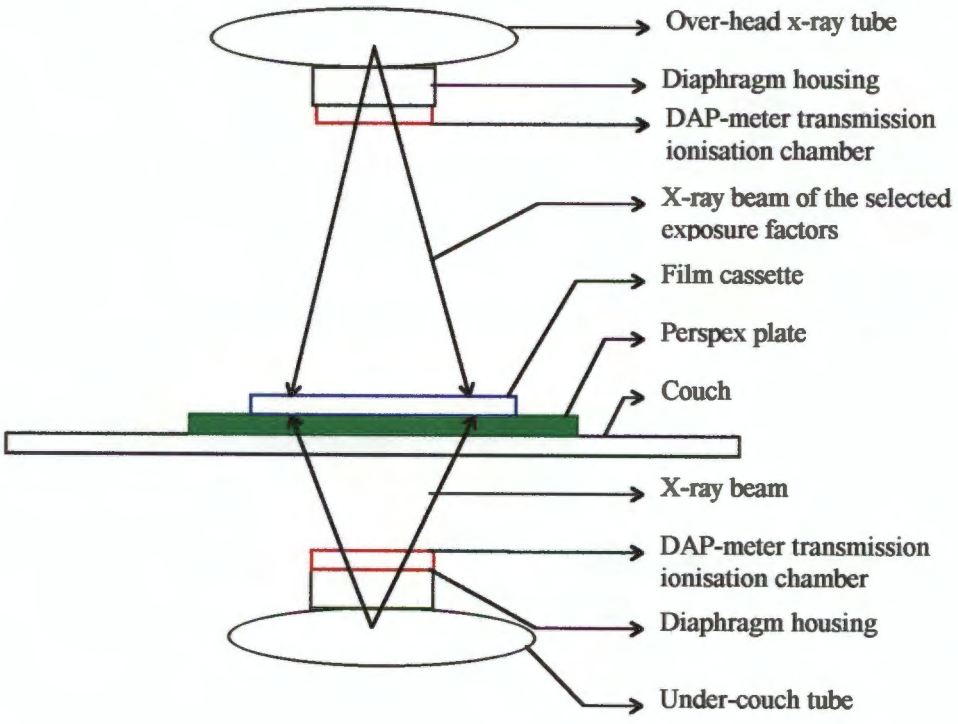


Figure 5.2: *Diagrammatic sketch of the set-up for calibration of the DAP-meter*



In order to establish the reliability of the DAP-meter readings relevant to the particular units a series of exposures were conducted, without a patient, on each unit (Appendix A3). The exposures selected were in the range of exposure options for the Ba E and similar exposures were used on each of the 3 units. Three settings of exposure factors were selected for the radiography views and 5 consecutive exposures were made. The DAP-meter reading for each of these was recorded. In the case of screening one set of exposure factors was set and 5 readings were taken following 1 minute of screening time for each reading. The % standard deviation was calculated for each set of 5 exposures and these demonstrated that for the radiography exposures the value is < 1 % in most cases. The screening exposure resulted in a % standard deviation of 2.04 % for A, 2.64 % for B and 0.77 % for C. These results demonstrated satisfactory reliability of the DAP-meter readings on the units used for measurements in this study.

5.4.5 X-ray Equipment Used

5.4.5.1 Unit A

Philips Diagnost 73

This is a diagnostic x-ray unit with an under-table x-ray tube assembly and over-table spot-film device. There is an overhead x-ray tube assembly and table bucky for standard radiography. The unit is controlled from the table-side.

Super 80 CP

For screening and all exposures using the over-table spot-film device, this unit provides automatic exposure settings, with manual adjustments if desired.

The programme setting for this study was; Colon - for all double contrast examinations.

The exposures using the overhead tube, with or without bucky, are manually set.

Film cassettes: 200 speed screen used for all exposures.

Note that this department does ***routine decubitus views*** at the end of the study which are taken out of bucky using a grid cassette with intensifying screens.

X-ray tube total filtration: 2.5 mm Al Equivalent on overhead tube and on undercouch tube.

SSD - 100 cm for overhead tube

SSD - 43 cm for undercouch tube

Technique factors

Screening kV and mA readings were recorded during the procedure in order to establish a realistic mean. The minimum readings taken on any patient were two, that is the highest and lowest factors. Up to seven readings were recorded on some patients where possible to do so. The accumulated screening time as indicated by the x-ray control was recorded.

Exposure factors of kV and mAs were recorded accurately for all exposures during the examination.

The film size was recorded in all cases. The total number of exposures was recorded

The beam projection was recorded in all cases for each exposure.

5.4.5.2 Unit B

Toshiba Fluorex DBA-300A

This is a diagnostic x-ray unit with over-table x-ray tube assembly. The unit can be controlled from the mobile unit which has a monitor for viewing as well as the controls or alternatively it can be operated from the remote control desk. There are undertable cut-film cassettes for hard copy film sizes other than the large 35 cm x 43 cm film. Taking 35 cm x 43 cm images requires the use of a storage phosphor screen cassette. The cassette is placed in a tray which slides into a track under the table. The images taken during screening are recorded with the aid of an electronic photospot system which can be copied onto film as required.

SID - 108 cm

Model KXO - 8 ON

This provides automatic exposure settings with manual setting if desired. The exposures for images on the electronic photospot system are all automatic and these are high kV, low mA exposures. The standard radiography exposures are set manually but this is infrequently done and only involved the cut-film views.

EPS 30

This is an electronic photospot system which is a digital video recorder used in conjunction with a radioscopic and fluoroscopic x-ray system. The maximum mA for spot filming and photospot can be set separately. The images are recorded on video and these can be manipulated when viewed. Hard copies can be made of the images if this is desired.

***User commands are received from*:**

X-ray system interface
Patient Data Entry Terminal (Link MC5)
In-room Table-side Panel
Review-room Remote Control Box with Track-ball
Infrared Remote Control Box

***Additional major components are*:**

Infrared Receiver Unit
Annotation Keyboard
In-room Monitor (TVM 210 MB)
Mainframe Unit
Review-room Monitor (TVM 150 MT)

***Film cassettes*:**

The 35 cm x 43 cm images are taken using Kodak Ektascan Storage Phosphor Screen and cassette. This system is approximately equivalent to a 300-speed film-screen combination.

The screen speed for the cut-film was unable to be confirmed. However the exposure factors indicate that it is a faster system as compared to the storage phosphor screen and is in the region of a 400-speed screen.

X-ray tube total filtration: 3.0 mm Al Equivalent

Technique factors

Screening kV and mA readings were recorded during the procedure in order to establish a realistic mean. The minimum readings taken on any patient were two, that is the highest and lowest factors. Up to seven readings were recorded on some patients where possible to do so. The accumulated screening time as indicated by the x-ray control was recorded.

Exposure factors of kV and mAs were recorded accurately for all exposures during the examination.

The film size was recorded in all cases and the total number of exposures.

The beam projection was recorded in all cases for each exposure.

5.4.5.3 Unit C:

Siemens Siregraph - D3

This equipment is a universal diagnostic x-ray unit with over-table x-ray tube assembly and under-table spot-film device, which is used during screening for spot films and also for the standard radiography views. The unit is microprocessor controlled and can be operated optionally from the table-side or from the remote control desk.

Polydoros 80S

This provides automatic exposure settings with manual adjustments if desired.

The programme settings for this study were; Barium Enema - for all double contrast examinations, Small Bowel - for the single contrast studies and Abdomen without contrast - was used by some radiographers for the overhead images.

***Film cassettes*:** 200 speed screen used for all exposures.

X-ray tube total filtration: 3.00 mm Al Equivalent.

SID - 115 cm

Technique factors

Screening kV and mA readings were recorded during the procedure in order to establish a realistic mean. The minimum readings taken on any patient were two, that is the highest and lowest factors. Up to seven readings were recorded on some patients where possible to do so. The accumulated screening time as indicated by the x-ray control was recorded.

Exposure factors of kV and mAs were recorded accurately for all exposures during the examination.

The film size was recorded in all cases and the total number of exposures.

The beam projection was recorded in all cases for each exposure.

Chapter 6

THE DETERMINATION OF GONAD DOSE

The GSD can be obtained with the aid of the following mathematical expression (Darby *et al*, 1980):

$$GSD = \frac{\sum_k \sum_l N_{kl} P_{kl} \overline{D_{kl}}}{\sum_k N_k P_k}$$

where N_{kl} is the number of individuals in the kth age-sex-race group who underwent an examination of type *l* during the year in question;

P_{kl} is the child expectancy of an individual in the kth age-sex-race group who underwent an examination of type *l*;

$\overline{D_{kl}}$ is the mean gonadal dose received by an individual in the kth age-sex-race group from an examination of type *l*;

N_k is the number of individual in the kth age-sex-race group in the population;

and P_k is the child expectancy of an individual in the kth age-sex-race group.

The child expectancy of an individual will generally not be independent of the type of examination. Certain types of examinations, for example, will be carried out only on individuals who are thought to have diseases which reduce fertility. In practice the determination of P_{kl} will present great difficulties, however, and approximations have to be applied. A great variation could be obtained for P_{kl}, since it would be seriously affected by the condition of the patients in the above-mentioned cases. It must be assumed therefore that $P_{kl} = P_k$ (Darby *et al*, 1980).

An individual may undergo an examination of type *l* more than once a year. If the repeat had to be conducted on a different patient, its contribution to the total genetic injury would have been the same. Such an examination is therefore to be considered as an examination on an additional individual in the N_{kl}-group.

Average technique factors calculated by Maree for the Ba E in the age group >15 years (Table 6.1) can be compared to the average values of the technique factors calculated for the present study (Table 6.2). The average values were used to calculate the gonad doses.

The "RADCOMP Entrance Skin Exposure Software Programme" of Nuclear Associates was used to produce parametric free air exposure (FAE) tables (Nuclear Associates and Zamenhof, 1990) based on doses from Table B.3, NCRP Report No. 102 (1989). In this table average air kerma rates produced by diagnostic x-ray equipment at certain distances from source to point of measurement are provided in centigray per 100 mAs.The additional information needed by RADCOMP was; phase (three phase for all units in this study), Radiography or Fluoroscopy, total filtration (2,5 mm Al for the undercouch tube and 3,0 mm Al for the overhead tube) and focus-chamber-distance. These factors were combined by RADCOMP using recognised standard physics formulae eg the inverse square law in order to calculate the dose at the skin entrance.

The calculations of skin entrance doses were done separately by RADCOMP for the AP, PA and Lateral views by using the values from Table 6.2. The mean screening current of 2.68 mA was used for the AP and PA. A screening current of 3.5 mA was used for the Lateral dose calculation. The free air exposure was calculated first at the image receptor and then by means of the inverse square law at the surface of the skin. An SSD of 81 cm was used for the AP, 83 cm for the PA and 72 cm for the Lateral in the calculations for the overhead tube. These values were obtained from the known SID value, the mean patient thickness (Table 6.3) for the appropriate view and the measured distance from the table-top to the image receptor. The patient thickness values were obtained from the measurement of all patients and the results are compared to those used by Maree in Table 6.3. The SSD for the undercouch tube was 43 cm for all views. The SID for the undercouch tube was taken as 73 cm for the AP and PA projections and 75 cm for the Lateral projection. These were obtained by adding the mean patient thickness, plus an estimated gap between the film carrier and the patient, to the SSD.

Skin entrance and gonad doses are given in Table 6.4 for Maree's study. After the skin entrance doses were calculated for the present study (Table 6.5 and 6.6), it was possible to calculate the gonad doses for males and females. A computer programme from the FDA, US Department of Health and Human Services, in the USA was used for this purpose (Peterson and Rosenstein, 1989). The following information is required to calculate the gonad doses for radiography and fluoroscopy of adult patients:

1. The examination (Barium Enema) and view (AP, PA and LATERAL)
2. Entrance exposure (free in air) at skin surface
3. SSD (source-skin distance for undercouch tubes too)
4. High voltage of tube (kV)
5. Half-value-layer (HVL) (Obtained from Table B.2. of NCRP 102)
6. Workload (mAs)

7. Film size (x-ray field size at image receptor)

8. Screening time

9. Thickness of patient (AP and LATERAL)

10. X-ray field location relative to anatomical landmarks

Peterson and Rosenstein developed a computer programme, in 1989, which makes an estimation of the absorbed doses to several tissues of a reference patient for a specified x-ray projection using tissue-air ratios. These ratios were previously generated by a Monte Carlo technique. The free-in-air exposure at the tissue plane is computed from the free-in-air exposure at the skin entrance, using the inverse square law. The absorbed dose to the tissue is the product of the exposure at the tissue plane and the tissue-air ratio. Tissue doses for a female are obtained by minor adjustments to the tissue doses computed for the male reference patient (Maree, 1995).

The same input data are required for fluoroscopic projections. The SID and the SSD are both required, since the patient, x-ray source and image receptor geometry may not be the same as that selected for radiographic projections. The dynamic components of a fluoroscopic examination is simulated with stationary x-ray fields.

Gonad doses were calculated for each of the views by means of the average technique factors in Table 6.2. The average gonad dose for the specific age-gender group (> 15 years, male or female) was obtained by multiplying the number of exposures for the group (total number of radiography exposures calculated for the male and female groups is given in Table 6.7) by the respective dose per exposure (Table 6.5 and 6.6). The resultant doses obtained were divided by the number of patients in the specific age-gender group (total number of male and female patients given in Table 6.8) and the fluoroscopy dose (Table 6.5) was added to this. This was done for each unit individually, for the equipment having an undercouch tube, the equipment having an overhead tube facility and the three units combined. The results are given in Tables 6.9 and 6.10. The overall error of the calculation of the average gonad doses given in Table 6.9 and 6.10 was estimated as being 25%.

The combined and undercouch average gonad results (Table 6.10) are lower than the results of Maree (Table 6.4) by a factor of 1.4 and 2 respectively. The overhead tube result (Table 6.10) is lower by a factor in the order of 3. Maree assumed all equipment to be undercouch. This may have been a correct representation of equipment at the time of his study, however all new equipment installed has a single overcouch tube for radiography and fluoroscopy. It is likely that this factor contributes to the high GSD found for the South African female population in Maree's study as compared to the GSD for females in several first world countries.

Table 6.1: *Average technique values for barium enema* (Maree, 1995)

(years)	View	mAs	*SD*	kV	*SD*	FFD (cm)	*SD* (cm)	SSD (cm)	*SD* (cm)	FieldX (cm)	*SD* (cm)	FieldY (cm)	*SD* (cm)	Fl (min.)	*SD* (min.)
>15	AP	58.3	*134.6*	95.8	*13.0*	99.6	*17.9*	57.8	*22.0*	31.1	*5.3*	37.2	*6.0*	6.1	*3.3*
	PA	140	*188.5*	106.5	*10.0*	77.1	*13.5*	43.6	*8.2*	22.4	*8.7*	31.1	*6.0*		
	LAT	291	*356.6*	111.8	*10.9*	80.0	*15.5*	43.5	*10.6*	24.8	*4.3*	30.8	*4.5*		

Table 6.2: *Average technique values for barium enema* (Present study)
(SSD and Fluoroscopy time is for Overhead tube)

Age (years)	View	mAs	± *SD*	kV	± *SD*	SID (cm)	± *SD*	SSD (cm)	± *SD*	FieldX (cm)	± *SD*	FieldY (cm)	± *SD*	Fl (min.)	± *SD*
>15	AP	23.7	*27.4*	104	*12.7*	112	*4.3*	81	*9.5*	25.2	*7.6*	30.1	*8.7*	2.9	*4.3*
	PA	45.5	*35.3*	97	*16.6*	108	*7.8*	83	*20*	29	*6.1*	33.6	*7*	1.8	
	LAT	46.7	*47.9*	112	*8.28*	112	*9.9*	72	*17*	24.3	*6*	30.3	*7*	1.2	

Fl (kV)	± *SD*	Fl (mA)	± *SD*
95		2.68	
95	*13.6*	2.68	*0.9*
110		3.5	

mAs workload
kV tube voltage
FFD focus-film-distance
SID source-image -distance
SSD source-skin-distance
SD standard deviation
Field X x-ray field in x-direction at image receptor
Field Y x-ray field in y-direction at image receptor
Fl(min) fluoroscopy time in minutes
Fl(kV) fluoroscopy tube voltage
Fl(mA) fluoroscopy tube current

Table 6.3: *Patient thickness*

	Age (years)	View	Patient thickness (cm)	
(Maree, 1995)		AP	24	
		LAT	31	
				±SD
(Present study)		AP	24	7.6
		PA	22	6.5
		LAT	30	5.2

Table 6.4: *Skin entrance and gonad doses for Barium Enema x-ray examination* (Maree, 1995)

		RADIOGRAPHY			FLUOROSCOPY				
Age (years)	**View**	**FAE** SE (mR)	**GD** male (mrad)	**GD** female (mrad)	**FAE** SE (mR)	**GD** male (mrad)	**GD** female (mrad)	**av. GD** male (mrad)	**av. GD** female (mrad)
	AP	2191	28	604					
>15	PA	10864	36	1672	85640	188	11026	**485**	**16111**
	LAT	24899	31	1426					

FAE free air entry dose
SE skin entry dose
GD gonad dose
av. GD average gonad dose
AP antero-posterior projection
PA postero-anterior projection
LAT lateral projection

Table 6.5: *Skin entrance and gonad doses for Barium Enema x-ray examination* (Present study)

OVERHEAD TUBE

Age (years)	View	RADIOGRAPHY FAE SE (mR)	RADIOGRAPHY GD male (μGy x 10^{-1})	RADIOGRAPHY GD female (μGy x 10^{-1})	FLUOROSCOPY FAE SE (mR)	FLUOROSCOPY GD male (μGy x 10^{-1})	FLUOROSCOPY GD female (μGy x 10^{-1})
	AP	530	4	147	8796	24	1907
>15	PA	857	6	195	5460	11	847
	LAT	1493	4	135	7731	14	674

FAE free air entry dose
SE skin entry dose
GD gonad dose
AP antero-posterior projection
PA postero-anterior projection
LAT lateral projection

Table 6.6: *Skin entrance and gonad doses for Barium Enema x-ray examination* (Present study)

UNDERCOUCH TUBE

Age (years)	View	RADIOGRAPHY FAE SE (mR)	RADIOGRAPHY GD male (μGy x 10^{-1})	RADIOGRAPHY GD female (μGy x 10^{-1})	FLUOROSCOPY FAE SE (mR)	FLUOROSCOPY GD male (μGy x 10^{-1})	FLUOROSCOPY GD female (μGy x 10^{-1})
	AP	1893	7	401	24416	35	3158
>15	PA	3095	14	535	60865	64	5383
	LAT	4205	4	211	36448	48	2305

FAE free air entry dose
SE skin entry dose
GD gonad dose
AP antero-posterior projection
PA postero-anterior projection
LAT lateral projection

Table 6.7: *Total number of radiography exposures calculated for the Male and Female groups according to centre and projection*

Centre	Antero-posterior view		Postero-anterior view		Lateral view	
	Male	Female	Male	Female	Male	Female
A/overhead tube	4	8	3	9	7	18
A/undercouch tube	5	6	20	45	7	18
B	66	45	18	15	22	16
C	67	146	27	87	14	43

Table 6.8: *Total number of Male and Female patients in the three centres*

Centre	Male	Female
A	3	7
B	6	4
C	8	22

Table 6.9: *Average gonad doses for the Unit A, B and C*
(Present study)

UNIT A		UNIT B		UNIT C	
av. GD male ($\mu Gy \times 10^{-1}$)	**av. GD** female ($\mu Gy \times 10^{-1}$)	**av. GD** male ($\mu Gy \times 10^{-1}$)	**av. GD** female ($\mu Gy \times 10^{-1}$)	**av. GD** male ($\mu Gy \times 10^{-1}$)	**av. GD** female ($\mu Gy \times 10^{-1}$)
339	**15937**	**127**	**6353**	**111**	**5439**

Table 6.10: *Average gonad doses for undercouch tube, overhead tube*
(Present study)

UNDERCOUCH TUBE		OVERHEAD TUBE		COMBINED	
av. GD male ($\mu Gy \times 10^{-1}$)	**av. GD** female ($\mu Gy \times 10^{-1}$)	**av. GD** male ($\mu Gy \times 10^{-1}$)	**av. GD** female ($\mu Gy \times 10^{-1}$)	**av. GD** male ($\mu Gy \times 10^{-1}$)	**av. GD** female ($\mu Gy \times 10^{-1}$)
339	**15937**	**118**	**5579**	**242**	**11185**

Chapter 7

DETAILED ANALYSIS OF BARIUM ENEMA DATA

The patient data for the Ba E examination in Maree's survey (Maree, 1995) was analysed for the purposes of the present study without the imputation of any missing data and with the exclusions as was explained in Chapter 4. This allowed for direct comparison of the parameters; number of patients, mean age, mean fluoroscopy time and mean number of exposures, which were not given in Maree's study, with the results for these parameters in the present study. Tables 7.1, 7.2 and 7.3 were constructed of the mean values and the standard deviation of each parameter from Maree's survey.

The average technique factors of the present study (Table 6.2) were used to calculate skin entrance and gonad doses as described in chapter 6. These values were then compared to the values in Maree's study for the same parameters in order to establish any differences that might contribute to or account for the high GSD in white females which was found in Maree's study.

The measured dose-area product recorded for individual exposures and fluoroscopy was used to calculate the air kerma at the skin entrance for the radiography and fluoroscopy components of a Ba E (7.12 of this chapter). These doses were used to calculate gonad dose in order to make a comparison of this important parameter with the results in Maree's study.

Finally the dose-area product values from the present study were used to motivate a national protocol for reference doses in South Africa.

7.1 Analysis of Barium Enema data from Maree's study

The data for Ba Es from Maree's survey was analysed for:

State Hospitals (Table 7.1)

Private Centres (Table 7.2)

Combined results (Table 7.3)

Maree raised the matter of the high percentage of white females in the Ba E sample. Table 7.2 shows that of the 115 patients from the private centres there were 80 females and of these 79 were white. Also of the 35 males, 32 were white. The small number of patients in the other race-gender groups is less likely to be a true reflection of patients presenting for Ba E in the country and more likely to be due to the fact that the largest number of patients was drawn from private centres in a racially segregated society. The sample of 55 patients from

State Hospital (Table 7.1) also indicates a number of 16 white females which is considerably more than any other race-gender group. As many of the State Hospitals were racially biased at the time of Maree's study the sample could be skewed towards drawing more white patients into the sample or the higher percentage of white females having Ba Es could be a correct representation of the health care opportunities and needs as well as an indication of the underprovision of radiology services to some of the people of South Africa.

Maree, as part of his study, calculated the frequency of radiological examinations for the entire population for a one year period and presented this information for race/gender groups. The percentage of the total for the eight race/gender groups is similar to the percentages of the sample in Maree's study. This is to be expected as the Ba E sample was used by Maree to calculate the frequency of this particular examination for the entire population for a one year period. Analysis of the Ba E sample from Maree's study shows that 56 % of the total number of patients are white female and only 5 % are black females. Although this present study was designed to investigate dose measurements and cannot be taken as a precise representation of the population attending for Ba Es in the country, it does indicate that the race/gender split in Maree's study was heavily weighted towards the white population and in particular white females.

Maree draws the conclusion that the frequency of Ba E examinations is not the cause of the exceptionally high GSD of white females. He continues by saying that the large doses involved in a Ba E are likely to be responsible for the large contribution of this type of examination to the GSD of white females. The results of the present study confirm that the average gonad dose for females is high in certain circumstances but not all. In fact the average gonad dose calculated for the unit utilising an undercouch tube is similar to the average gonad dose calculated by Maree. The results are 15937 μGy x 10^{-1} (Table 6.7) and 16111 μGy x 10^{-1} (Table 6.3) respectively. It is the dose due to fluoroscopy with the undercouch tube that is as high as in Maree's study. Table 6.3, 6.4 and 6.5 show that the overhead tube gives a lower ovary dose for fluoroscopy and that the radiography doses are lower for overhead than for the undercouch tubes. Clearly the mAs is the reason for this and Table 6.1 and 6.2 show that the mAs is higher for all views in Maree's study. The results of this study demonstrate that lower doses are possible for the Ba E examination and that Maree's statement that lower doses for this examination could favourably influence the GSD is a reality.

The mean fluoroscopy time and mean number of exposures were calculated as an indication of technique and dose to the patients for Maree's sample and the present study. These will be compared later in this chapter.

7.2 Age

The patients in the sample in the present study had an age range of 21 years to 80 years with the mean being 55.6 years (Table 7.4). This is in agreement with the range and mean of Maree's sample which are 19 years to 85 years and 52.9 years respectively (Table 7.3).

7.3 Mass

The mean mass of the sample in the present study was 69.5 kg (Table 7.4) and the range was 43 kg to 105 kg. In Maree's study the range of the mass was 45 kg to 95 kg and the mean mass was 68.5 kg (Table 7.3). This again indicates a similarity. Figure 7.1 shows a plot of DAP against patient mass for Unit C. There appears to be no clear correlation between the DAP reading and patient mass, leading to a correlation coefficient between the two variables of 0.49. The female and male mass calculation is shown in Table 7.3 for Maree's study and Table 7.10 for the present study. Male mass is 71.39 kg and 73.35 kg and the female mass is 67.03 kg and 67.52 kg respectively. These values are clearly similar. The mass of a male quoted by Cember as the reference person 70 kg while the mass given for the reference female is 58 kg (Cember, 1996). This indicates that the South African female weighs more than the reference female. However as dose is not clearly related to the mass of the patient for Ba Es this is not thought to contribute to the higher female doses in this country as compared to the first world countries.

7.4 Fluoroscopy time

The fluoroscopy time varied from patient to patient and the results below are the mean and the range of the 3 centres where measurements were done for the present study.

A : 3.43 minutes (1.50 min. to 5.50 min.)

B : 5.87 minutes (3.07 min. to 8.06 min.)

C : 6.63 minutes (3.00 min. to 30.00 min.)

The over-all mean fluoroscopy time is 5.84 minutes. Table 7.1 and 7.2 demonstrate that the mean fluoroscopy time varied from centre to centre in Maree's study with a range of 0.6 minutes to 9.5 minutes. The combined mean value for screening time was 4.23 minutes for patients where time was given. However Maree imputed missing values and for the calculations in his study a fluoroscopy time of 6.1 minutes was used. The value used by him is therefore very close to the value of the present study.

Table 7.5 is a comparison of the screening time for this study with other studies and it indicates that the South African fluoroscopy time for this examination is higher than other published data.

Martin (1994) stated that for Ba Es the contribution to mean dose from fluoroscopy and radiography varied significantly between different units with the contribution from fluoroscopy ranging from 24-57 %. Martin makes the statement that this is related to the fluoroscopy time. An estimate of the contribution to the mean dose from fluorosopy in the present study results in values of 68 % for A, 54 % for B and 63 % for C.

7.5 Total number of exposures

The mean and range of the total number of exposures at the 3 centres where measurements were done in this study are:

A : 15.10 (12 to 18)

B : 18.20 (12 to 21)

C : 12.80 (10 to 17)

The combined mean is 14.34 while in Maree's study the mean is 8.78. The higher figure in the present study is not limited to the values of one centre as all three are higher than the mean value and the values for the individual centres in Maree's study. This result could reflect a regional variant or may be due to the small sample of centres in this study. Further recordings would be necessary to conclusively explain this difference. In a comparison with results of published data the total number of exposures (spot exposures plus radiographs) was investigated and Table 7.6 is the summary.

The variation in the total number of exposures is demonstrated by the range in the present study of 10 to 21. As the dose to the ovary is in the region of 0.002 Gy per exposure (Hall, 1994) the effect of an increase in the total number of exposures can be considerable. The comment in the NCRP-102 report should be heeded by all doing a Ba E. This is that in procedures where spot film cameras are used and where multiple images are easily obtained, the radiologist must be fully aware of the manner in which exposures are made and must exercise great care to assure that only the required exposures are made (NCRP-102, 1989).

7.6 Dose-area product

The dose-area product measurements in this study followed the trend of the NRPB survey which showed a large variation in the distribution of dose-area product for Ba Es within the same centre and when comparing the centres involved in the survey (Figure 7.2). The lowest recorded dose was 15.66 Gy cm^2 and the highest was 162.4 Gy cm^2. The measured dose-area product is given in Table 7.4 and 7.71 and in Figure 7.3. The mean demonstrates that B and C are similar but that A is higher by a factor of almost 2. The percentile calculations indicate that A has the highest median value followed by B and then C. The combined median is

48.21 Gy cm^2 and the range is shown by the maximum and minimum readings at each centre. These results will be discussed later in this chapter with consideration being given to possible reasons for the differences.

7.7 Fluoroscopy Exposure Factors

The mean fluoroscopy kV and mA factors for the present study are given in Table 7.8. The mean fluoroscopy current is 2.3 mA for A, 2.97 mA for B and 2.73 mA for C with a combined mean of 2.68 mA. It is noted that the standard deviations for these results is <1.

This compares well with the fluoroscopy current of 3 mA used by Maree for the dose calculations in his study (Maree, 1995).

7.8 Radiography Exposure Factors

Table 7.9 gives the break-down of the mean kV and mAs for the Antero-posterior (AP), Postero-anterior (PA) and Lateral (LAT) projections for the present study. These results are shown in Figure 7.2. The mAs is significantly different between the 3 centres and this factor is considered to be the major contributor to the higher dose-area product measurements at A. The equipment differences are considered to be responsible for this variation and they will be further discussed in Chapter 8.

7.9 Race/Gender

Table 7.10 gives the number of patients by race and gender for this study. Tables 7.11 and 7.3 show the parameters; age, mass, fluoroscopy time in minutes, total number of exposures and dose-area product for the present study and the study of Maree. In Maree's study the White female group has a mean age which is somewhat lower than that of the other female groups. The mean mass of the White females is similar to this value in the other female groups except for the Asian female group which is higher but has only one patient in the sample. The mean screening time is lower for the White female group except again for the one Asian female. The total number of exposures varies from patient to patient and the White female group has a higher value than the Black and Asian group but a lower value than the Coloured group. Consideration of the same parameters for the present study show that the mean age of the White female group to be similar to two of the groups with the Black females showing a higher value. The mean mass varies for all groups. Asian females having a higher value than the other female groups. The mean screening time also between the female groups with the White females having a higher value. The total number of exposures is similar in all groups. Comparison of the White female group in the two studies shows the mean age and mass to be similar. The mean screening time and total number of exposures is lower in Maree's study.

Although the groups are not equally well represented the results infer that dose is not related to race as the values are not consistently higher or lower for patients of

one of the race groups. However the mean values of the present study show the White and Coloured female groups to have a higher dose than the other two groups. This would require further measurements, with larger patient numbers to draw accurate conclusions. Skin dose is related to many factors including; the equipment, the technique, physiological and pathological variables. Sex is a factor in the case of organ dose, particularly the gonad dose. If DAP readings are used as an indication of radiation risk, race need not be recorded or considered. In South Africa, however, the child expectancy varies according to race and therefore if GSD is to be calculated the race remains a relevant factor.

7.10 Radiologist technique

Figure 7.5 demonstrates the variation in DAP for the various radiologists in the present study. The DAP reading, however, is not necessarily only related to a particular radiological technique as other factors such as the equipment, patient anatomy and pathology and radiographer technique influence the dose-area product. The choice of the technique parameters is also partly dictated by the individual patient, partly by the limitations of the available equipment and also the technique preferences and expertise of the radiologists and radiographers involved. The importance of the contribution of each to patient dose is difficult to evaluate as it is impossible to remove the other variables affecting dose. However Figure 7.5 demonstrates the variation in DAP measurements within the three centres in the present study. Although for some radiologists the number of examinations where measurements were taken was only one or two, for some it involved from 3 up to a maximum of 13 patients. It is necessary to view this chart by comparing only the radiologists using a particular x-ray unit in order to remove the critical variable of equipment and then to be cautious in any conclusions drawn. Martin considered that equipment related factors had a greater influence on patient doses than radiologists' techniques (Martin, 1994). It remains though an important factor and the radiologist does play a key role in keeping the dose to the patient as low as reasonably achievable.

7.11 Average technique factors

The recorded data was used to construct tables that comprised the average values of the technique factors for the present study. These are given in Table 6.2 which is arranged according to projection for the >15 year age group. Table 6.1 is similar data from the study of Maree (Maree, 1995). These average technique values were used to calculate the skin entrance doses and gonad doses as described in Chapter 6. The radiography mAs values are significantly different to the corresponding values of Maree's (Figure 7.4). This factor is responsible for dose according to the formula in 3.2.2.1 and is considered as a major contributor to the difference in dose values between the two studies. The SSD value is also greater in the present study for all views. Maree made the assumption that screening was largely with equipment having an undercouch tube and therefore the SSD is less than in the present study where 2 of the 3 units utilise overcouch tubes for screening and radiography. The screening time in this study was divided between

the 3 projections as shown in Table 6.2. These times were used for the FAE calculations for the overhead tubes. In the case of the undercouch equipment the average screening time for the Lateral was as for the overcouch equipment. The AP and PA average screening times were however swopped about. The calculations were done accordingly. The calculated average fluoroscopy exposure factors given in Table 6.2 were used for the AP and PA projections. The exposure factors for fluoroscopy in the lateral projection are higher and the factors 110 kV and 3.5 mA (Table 6.2) were assumed from doses recorded with the patient in the lateral position although the average values could not be precisely calculated from data recorded intermittently during the dynamic screening process.

7.12 Dose-area product used to calculate air kerma at skin entrance

The aim of this study was to record the total DAP-meter reading for complete Ba E examinations. However during the measurement procedure it was possible to record dose-area product readings for individual image exposures on some occasions and also to record readings for screening only over a given time period. These readings were used to calculate the air kerma at the level of the beam entry on the skin surface for the given radiographic exposure or screening period. The image receptor size was known as well as the SID and the SSD. These factors were used to calculate a field size at the level of the skin surface by using the following formula:

$$A_2 = A_1 \times (X^2 / Y^2)$$

A_2 : Area at skin surface

A_1 : Area at image receptor

X^2 : SSD squared

Y^2 : SID squared

The average beam area at the skin surface was 829 cm^2 for the present study. The equivalent parameter had a value of 841 cm^2 for the Ba E in the NRPB survey (Shrimpton *et al*, 1986).

The area A_2 could then be used to calculate the exposure in Gy at the skin surface by the use of the formula:

$$D = DAP / A_2$$

D : Dose in Gy

DAP : Dose-area product in Gy cm^2

A_2 : Area at skin surface

The results of these calculations are given in Table 7.12 and 7.13 together with the FAE results of the calculations as described in Chapter 6 (Table 6.5 and 6.6). The programme used for the FAE calculations recorded the result in mR and for ease of comparison these results were converted to Gy using the conversion factor 8.77 mGy/R as applied in the European inter-comparison of diagnostic dosemeters (Kramer, 1992).

The similarity in the values between the present study and that of Maree for the radiography is noted as is the difference in the calculated FAE using the average exposure factors and the skin entrance dose calculated from the dose-area product for fluoroscopy (Tables 6.5, 6.6, 7.12 and 7.13). The explanation for this is complex and should a correlation be required then further investigation is recommended in order to establish the differences in the two methods more precisely. It is however possible to identify some of the factors that may contribute to the differences in the FAE and Air kerma at skin entrance and this is discussed in Chapter 8.

A nation wide survey in the US was carried out using a fluoroscopic phantom and a 1.6 mm copper filter which simulated the use of barium contrast medium in order to evaluate upper gastrointestinal tract fluoroscopy. The air kerma results are of relevance to compare to those of this study although the examination is not equivalent in all ways. The results were (Suleiman *et al*, 1997):

> Average air kerma rates measured 1 cm above the tabletop, free in air, were 64 mGy/min when the copper filter was used. The minimum being 6.08 mGy/min and the maximum 182.49 mGy/min.
>
> The average air kerma rates for fluoroscopy in the present study fall within the lower range of the US survey by Suleiman as they are 13.4 mGy/min, 8.4 mGy/min and 8.8 mGy/min in the three centres respectively. The minimum was 4.71 mGy/min and the maximum was 16.99 mGy/min.
>
> The mean doses for the standard radiography views in a Ba E examination and the dose per minute for screening is given in Table 7.14 for each of the units involved in this study.
>
> The average entrance air kerma, free in air, for radiographs in Suleiman's survey was 3.4 mGy. The minimum being 0.33 mGy and the maximum being 41.84 mGy.
>
> The skin entrance dose in the present study, had a minimum of 0.4 mGy and a maximum of 6.7 mGy.

The screening and the standard radiography measurements were possible to record on frequent occasions during the present study therefore the doses calculated for

these are considered to be more precise than for the spot film exposures which could only be infrequently recorded.

7.13 The effect of single versus double contrast on dose

Double contrast Ba Es are the standard for this examination at the three centres investigated for this study and the number of single contrast studies was small.

A : 0/10

B : 1/10

C : 3/30

The comparison of the effect of the use of single or double contrast on dose is only possible for centre C. Table 7.15 shows the results of this comparison.

This small study indicates that for a similar or lesser fluoroscopy time and similar total number of exposures the dose-area product is higher for single contrast studies. A possible explanation for this is that the automatic exposure devices in use on this equipment give higher exposures in the single contrast studies as the barium is consolidated. Conversely the barium plus air in the double contrast study offers a lower density and therefore lower exposure factors are applied. This factor would need further investigation to confirm this. However as the number of single contrast studies is apparently small the effect of this examination on the GSD is likely to be negligible and can be ruled out as a factor in the results of Maree's study.

7.14 Summary

The variables investigated for contribution to dose were:

- patient age
- patient mass
- fluoroscopy time
- total number of exposures
- fluoroscopy exposure factors
- radiography exposure factors
- race and gender
- radiologist
- single versus double contrast technique

The variables that are of most significance with regard to the contribution to dose appear from the comparison of the present study to previous studies to be:

- fluoroscopy time
- total number of exposures
- radiography mAs

Table 7.1: *State Hospital Data for Barium Enema Examinations* (Maree, 1995)
(Refer to Table 7.16 for the race/gender codes)

CENTRE	No. of PATIENTS	MEAN AGE (years)	± SD	MEAN MASS (kg)	± SD	MEAN SCREEN TIME (minutes)	± SD	MEAN EXPOSURES	± SD
1.1	7	51.43	16.49	65.14	10.37	4.3	1.21	4.71	0.95
1.2	4	66.75	9.00	67.00	11.53	2.01	0.37	6.25	0.96
1.3	5	56.40	18.17	77.25	14.61	5.80	1.64	12.2	5.26
1.4	17	52.94	16.37	67.00	10.44	8.30	3.45	13.5	3.79
1.5	11	72.09	6.64			4.10	1.25	8.73	2.05
1.6	3	50.33	31.50	65.33	23.35	4.67	0.29	12.33	2.52
1.7	4	46.25	19.86	56.25	7.50	3.00	1.41	3.00	
1.8	4	66.50	19.76	63.75	7.50	5.38	1.11	6.00	1.15
MEAN STATE	55	58.42	17.62	66.15	11.84	5.47	2.97	9.73	4.47
FEMALE	30	62.03	18.05	66.00	12.55	4.90	1.85	9.10	3.79
MALE	26	54.39	16.55	66.33	11.32	6.11	3.80	10.52	5.18
R/G 8	8	53.63	16.94	61.43	6.68	5.49	2.16	6.75	3.73
R/G 2	16	65.88	18.69	64.44	15.71	4.42	1.60	9.50	3.08

RACE/GENDER	
1	10
2	16
3	6
4	4
5	4
6	1
7	6
8	8

Table 7.2: *Private Practice Data for Barium Enema Examinations* (Maree, 1995)
(Refer to Table 7.16 for race/gender codes)

CENTRE	No. of PATIENTS	MEAN AGE (years)	± SD	MEAN MASS (kg)	± SD	MEAN SCREEN TIME (minutes)	± SD	MEAN EXPOSURES	± SD
2.1	5	56.40	*26.60*	68.00	*12.00*	5.00	*1.22*	4.20	*1.64*
2.2	4	37.25	*11.50*	71.50	*8.10*	1.50	*0*	6.00	*0*
2.3	38	52.58	*14.09*			5.00	*0*	7.18	*2.17*
2.4	8	52.75	*8.91*	63.33	*9.14*	3.38	*1.07*	8.63	*0.92*
2.5	32	47.63	*18.36*	69.77	*12.37*	3.17	*1.64*	10.31	*1.73*
2.6	16	51.63	*18.69*	70.13	*12.51*	2.29	*0.97*	9.63	*2.45*
2.7	12	47.67	*14.12*	72.91	*11.01*	2.65	*1.07*	7.42	*0.67*
MEAN									
PRIVATE	115	50.20	*16.35*	69.77	*11.62*	3.64	*1.54*	8.35	*2.47*
FEMALE	80	48.95	*16.13*	67.43	*10.64*	3.44	*1.61*	8.50	*2.39*
MALE	35	53.06	*16.72*	75.95	*12.12*	4.07	*1.28*	8.00	*2.67*
R/G 8	0								
R/G 2	79	48.89	*16.22*	67.77	*10.45*	3.45	*1.62*	8.56	*2.35*

RACE/GENDER	
1	32
2	79
3	2
4	1
5	1
6	0
7	0
8	0

Table 7.3: *Combined State and Private Data for Barium Enema Examinations* (Maree, 1995)
(Refer to Table 7.16 for race/gender codes)

	No. of PATIENTS	MEAN AGE (years)	± SD	MEAN MASS (kg)	± SD	MEAN SCREEN TIME (minutes)	± SD	MEAN EXPOSURES	± SD
TOTAL	170	52.86	*17.16*	68.51	*11.77*	4.23	*2.27*	8.78	*3.28*
MALE	61	53.62	*16.52*	71.39	*12.57*	4.94	*2.82*	9.00	*4.02*
FEMALE	109	52.43	*17.56*	67.03	*11.14*	3.83	*1.79*	8.66	*2.82*
MW	42	55.29	*16.43*	74.36	*11.93*	4.69	*2.60*	8.86	*3.77*
FW	95	51.75	*17.37*	67.57	*11.74*	3.61	*2.04*	8.72	*2.93*
MC	8	42.50	*11.70*	74.14	*13.42*	6.81	*4.46*	11.75	*5.26*
FC	5	60.80	*16.66*	66.00	*14.75*	5.54	*1.98*	11.60	*4.62*
MA	5	54.20	*16.60*	60.00	*0*	3.90	*1.34*	9.50	*2.12*
FA	1	66.00	*0*	78.00	*0*	2.80	*0*	4.00	*0*
MB	6	56.33	*20.49*	63.00	*12.00*	5.07	*1.86*	6.17	*2.4*
FB	8	53.63	*16.94*	61.43	*6.68*	5.49	*2.16*	6.75	*3.73*

Table 7.4: *Patient number, Age, Mass, Fluoroscopy time, Total number of Exposures and DAP for the 3 centres individually and combined* (Present study)

CENTRE	No. of PT.	MEAN AGE (years)	± SD	MEAN MASS (kg)	± SD	MEAN FLUORO. TIME (minutes)	± SD	MEAN NUMBER EXP.	± SD	DAP Gy cm^2	± SD
A	10	44.77	*17.17*	63.90	*10.42*	3.43	*1.46*	15.10	*2.02*	99.69	*21.3*
B	10	56.80	*13.92*	81.00	*10.17*	5.87	*1.59*	18.20	*2.70*	56.57	*24.55*
C	30	58.83	*14.45*	67.53	*11.26*	6.63	*5.26*	12.80	*1.75*	51.94	*32.19*
Combined	50	55.60	*15.63*	69.50	*12.24*	5.84	*4.34*	14.34	*2.92*	62.41	*34.13*

Table 7.5: *Mean screening time in minutes*

Present study (SA)	Broadhead 1995 (UK)	Martin 1994 (UK)	Maccia 1988 (France)	Wall 1980 (UK)
5.84	2.8	2.34	3.12	3.06

Table 7.6: *Mean number of exposures (spot plus standard)*

Present study 1997 (SA)	Broadhead 1995 (UK)	Martin 1994 (UK)	Maccia 1988 (France)	Wall 1984 (UK)	Wall 1980 (UK)
14.34	9.5	10.24(1.94) (decubitus)	9.5	6.7	7.78

Table 7.7: *Results of dose-area product measurements as percentile*

UNIT	Minimum Gy cm^2	1st Quartile Gy cm^2	Median Gy cm^2	3rd Quartile Gy cm^2	Maximum Gy cm^2
A	83.29	84.08	88.42	109.32	139.52
B	24.4	40.53	62.86	64.65	108.3
C	15.66	32.43	40.93	66.51	162.4
Combined	15.66	34.62	48.21	84.27	162.4

Table 7.8: *Fluoroscopy kV and mA for the 3 centres individually and combined*

CENTRE	No. of PT.	MEAN FLUORO. kV	± SD	MEAN FLUORO. mA	± SD
A	10	85.1	*11.7*	2.30	*0.64*
B	10	105.0	*12.4*	2.97	*0.67*
C	30	94.9	*11.6*	2.72	*0.94*
Combined	50	95.27	*13.63*	2.68	*0.85*

Table 7.9: *Radiography kV and mAs for AP, PA and Lateral projections for the 3 centres individually and combined*

CENTRE	No. of Pts.	MEAN AP kV	± SD	MEAN AP mAs	± SD	MEAN PA kV	± SD	MEAN PA mAs	± SD	MEAN LAT kV	± SD	MEAN LAT mAs	± SD
A	10	82	*12.84*	52.7	*15.2*	85	*9.62*	63.70	*29.0*	110	*56.47*	56.47	*50.6*
B	10	102	*12.33*	14.2	*24.4*	99	*14.3*	38.10	*38.1*	114	*6.27*	8.84	*3.86*
C	30	107	*10.24*	25.5	*27.3*	105	*16.2*	35.40	*33.7*	113	*5.5*	62.86	*48.2*
Combined	50	104	*12.73*	23.71	*27.37*	97	*16.63*	45.5	*35.28*	112	*8.38*	46.57	*47.9*

Table 7.10: *Total Patient Numbers by Race and Gender*
(Refer to Table 7.16 for race/gender codes)

CENTRE	NUMBER OF PATIENTS BY RACE AND GENDER							
	1	2	3	4	5	6	7	8
A	0	2	2	4	0	0	1	1
B	2	1	2	2	2	1	0	0
C	2	7	2	10	2	3	2	2
Combined	4	10	6	16	4	4	3	3

Table 7.11: *Patient number, Age, Mass, Fluoroscopy time, Total number of Exposures and DAP by Race Group* (Present study)
(Refer to Table 7.16 for race/gender codes)

R/G	No. of PT.	MEAN AGE (years)	± SD	MEAN MASS (kg)	± SD	MEAN FLUORO. TIME (minutes)	± SD	MEAN No. of EXP.	± SD	MEAN DAP Gy cm^2	± SD
MW	4	62.00	13.98	85.25	16.86	13.33	11.39	16.00	3.92	104.46	47.25
FW	10	54.27	*16.73*	64.00	*9.15*	6.80	*4.16*	14.36	*2.87*	66.41	*26.96*
MC	6	53.33	*18.67*	71.83	*11.00*	5.20	*1.80*	15.67	*3.56*	72.86	*40.76*
FC	16	53.47	*17.17*	69.67	*13.57*	4.43	*1.32*	13.67	*2.58*	61.66	*34.54*
MA	4	60.50	*12.26*	69.25	*7.23*	4.76	*1.74*	16.00	*1.83*	34.17	*8.17*
FA	4	58.00	*11.63*	73.75	*8.54*	4.64	*1.78*	13.25	*4.57*	43.83	*13.12*
MB	3	45.67	*17.04*	66.00	*3.61*	4.50	*2.71*	12.67	*0.58*	52.31	*27.78*
FB	3	67.33	*9.02*	61.33	*14.05*	5.00	*0.17*	13.67	*1.53*	47.09	34.17
Male	17	55.71	*15.71*	73.35	*12.37*	6.89	*6.36*	15.29	*3.02*	67.56	41.47
Female	33	55.55	*15.83*	67.52	*11.87*	5.30	*2.77*	13.85	*2.79*	59.76	30.03
Total	50	55.60	*15.63*	69.50	*12.24*	5.84	*4.34*	14.34	*2.92*	62.40	*34.11*

Table 7.12: *Air-kerma at level of skin surface calculated from dose-area product compared to the FAE calculated from average exposure factors*

OVERHEAD TUBE

		RADIOGRAPHY (per exposure)			FLUOROSCOPY (total time)		
Age (years)	**View**	***FAE SE*** (Gy)	**AIR KERMA AT SKIN ENTRANCE** B (Gy)	C (Gy)	***FAE SE*** (Gy)	**AIR KERMA AT SKIN ENTRANCE** B (Gy)	C (Gy)
	AP	*0.0047*	0.0031	0.0042	*0.0771*	0.0244	0.0255
>15	PA	*0.0075*	0.0037	0.0050	*0.0479*	0.0151	0.0158
	LAT	*0.0131*	0.0093	0.0120	*0.0678*	0.0101	0.0106

Table 7.13: *Air-kerma at level of skin surface calculated from dose-area product compared to the FAE calculated from average exposure factors*

UNDERCOUCH TUBE

		RADIOGRAPHY (per exposure)		FLUOROSCOPY (total time)	
Age (years)	**View**	***FAE SE*** (Gy)	**AIR KERMA AT SKIN ENTRANCE** A (Gy)	***FAE SE*** (Gy)	**AIR KERMA AT SKIN ENTRANCE** A (Gy)
	AP	*0.0166*	0.0079	*0.2141*	0.0482
>15	PA	*0.0271*	0.0110	*0.5338*	0.0778
	LAT	*0.0369*	0.0170	*0.3196*	0.0169

Table 7.14: *Mean Air kerma at the beam entry level for A, B and C*

View	STANDARD RADIOGRAPHY		
	A (Gy/exp.)	B (Gy/exp.)	C (Gy/exp.)
AP	0.0033	0.0041	0.0024
PA		0.0038	0.0015
PA 30°	0.0043	0.0036	0.0028
LAT. DEC.	0.0009		
	FLUOROSCOPY		
	A (Gy/min.)	B (Gy/min.)	C (Gy/min.)
	0.0134	0.0084	0.0088

Table 7.15: *Comparison for Double versus Single Contrast for Centre C*

	Fluoroscopy (min)	Total number of Exposures	DAP (Gy cm^2)
Double Contrast	5.93	12.62	46.48
Single Contrast	4.90	12.33	62.38

Table 7.16: *Race/Gender Codes*

Gender and Race	Code
MW	1
FW	2
MC	3
FC	4
MA	5
FA	6
MB	7
FB	8

F ⇒ female
M ⇒ male
A ⇒ Asian
B ⇒ Black
C ⇒ Coloured
W ⇒ White

Figure 7.1: *DAP versus patient mass for Unit C*

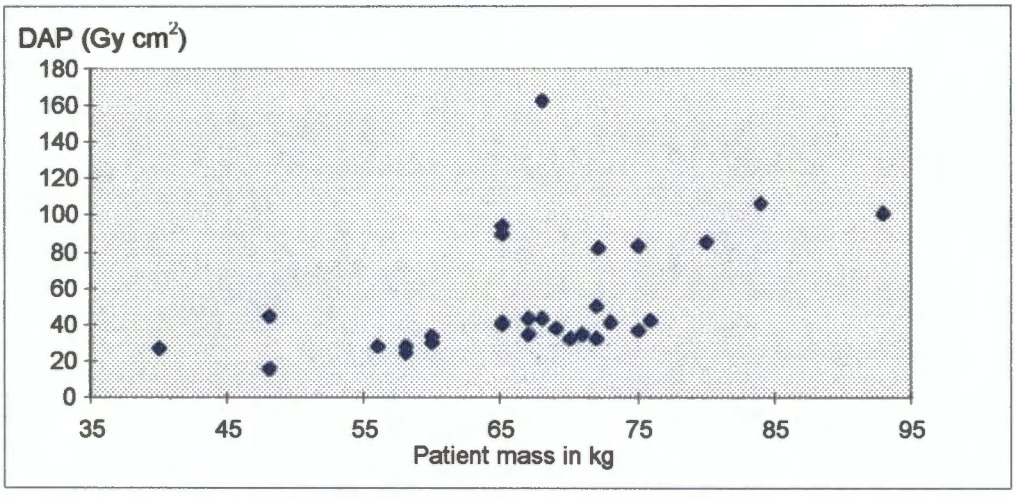


Figure 7.2: *Distribution of DAP readings*

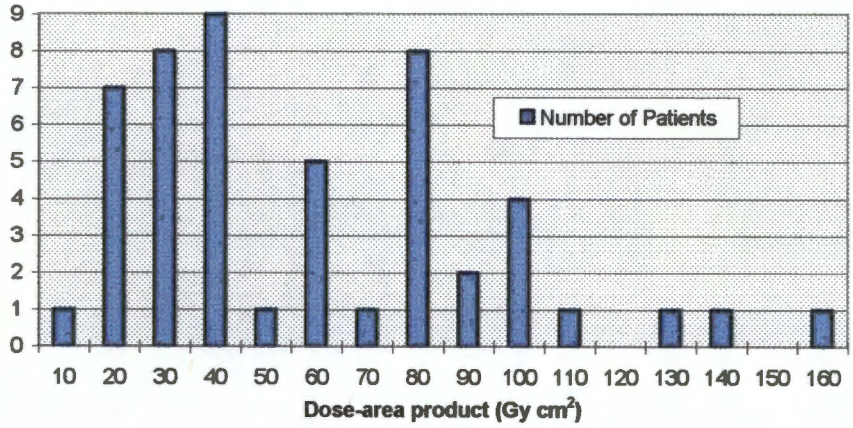


Figure 7.3: *Fluoroscopy and Radiography Exposure Factors for Unit A, B and C*

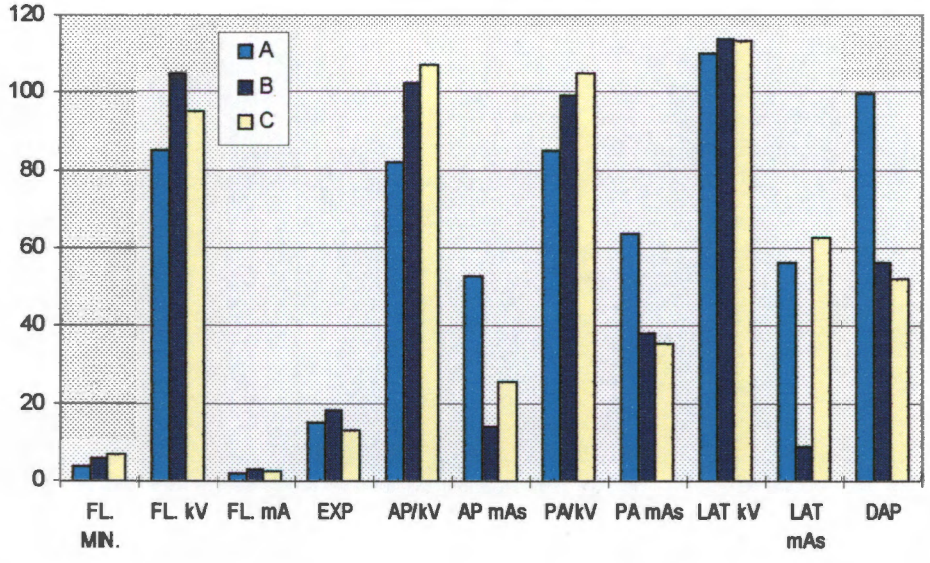


Figure 7.4: *Combined Fluoroscopy and Radiography Factors of the present study (*Total*) compared to the study of Maree (*GM*)*

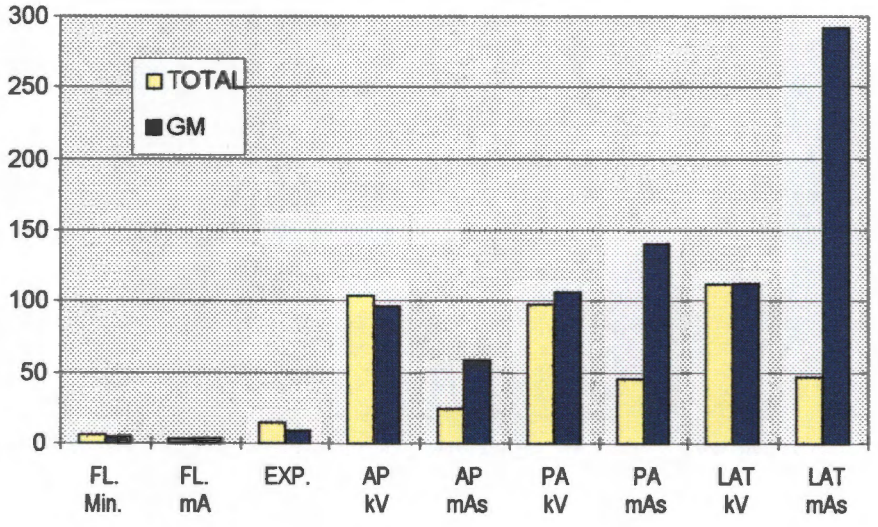
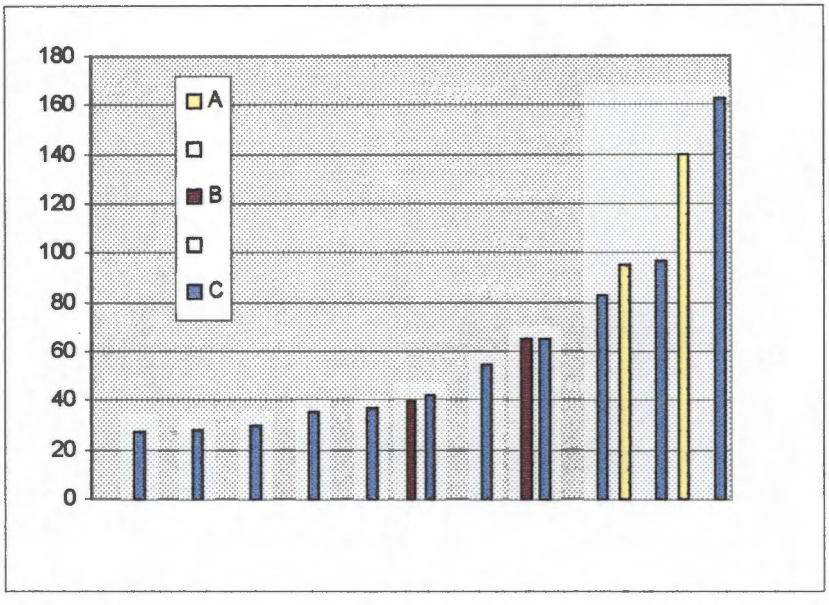


Figure 7.5: *Mean dose-area product (Gy cm^2) for individual radiologists at centres A, B, and C*



Chapter 8

DISCUSSION

8.1 Results of the present study compared to Maree's and other studies

The main objective of this study was to identify possible reasons for the high contribution of South African white females to the GSD (Figure 1.1) and in particular to investigate possible reasons for the very high contribution to the GSD in this race/gender group from the barium enema x-ray examination (Figure 1.3). Comments have been made during earlier chapters as possible factors became evident, however, it is appropriate to summarise these parameters here in order to give an over-view of the results in this study which relate particularly to this matter.

8.1.1 Average technique values

Table 6.1 and 6.2 record the average technique factors for Maree's and the present study respectively. The two parameters which are clearly different are the SSD and the mAs for all the radiography projections.

The increase in SSD in the present study is due to the SID for the equipment with overhead tubes. The SID for the undercouch tube is similar to that of Maree's. The reason for Maree's value being lower is that he made the assumption that all equipment had undercouch tubes. The advantage of an overhead tube is that the tube can be placed further from the patient which results in lower skin exposures (Johns *et al*, 1983). The shorter SSD would therefore account for a somewhat higher dose. In the present study the undercouch equipment (Unit A) with a shorter SSD records a higher dose-area product than the overhead tube equipment (Units B and C) operating at a larger SSD (Table 7.6).

Dose is linearly related to mAs and average values for this parameter are between 2 and 4 times higher in Maree's study than in the present study (Figure 7.3). It appears to be likely that the mA was incorrectly recorded under mAs by some of the radiographers participating in Maree's study and this could account for the high values and the large standard deviation found by him for this parameter. Doubling the mAs results in double the dose and this would make a difference in the calculation of FAE and therefore accounts in part for the higher doses calculated from Maree's average values as compared to the FAE calculated from average values for the present study.

8.1.2 Age

Age was shown to be similar in Maree's and the present study (Table 7.3 and 7.6) and it does not warrant further discussion.

8.1.3 Mass

Patient mass was also similar for Maree's and the present study (Table 7.3 and 7.6). In addition a correlation between patient mass and dose-area product was not demonstrated for the present study (Figure 7.1).

8.1.4 Fluoroscopy time

The mean fluoroscopy time of 6.1 minutes used by Maree is similar to the mean fluoroscopy time of 5.9 minutes for the present study. Table 7.4, however, shows that the mean screening time in the present study is higher than for studies in the UK and France. This could be partially responsible for the higher GSD demonstrated by Maree as compared to the UK and France (Figure 1.1). In attempts to reduce patient dose from barium enemas in South Africa this is clearly a factor for attention.

8.1.5 Total number of exposures

The mean of the total number of exposures was the only parameter that had a value higher for the present study than in Maree's study. The values were 14 and 9 respectively. Table 7.5 shows the comparison of this value for the present study and 5 other studies. In fact the value from Maree's work is similar to the studies in the UK and France and is therefore not likely to be a contributor to the higher GSD for South Africa as compared to these two countries. Again it is clear that attempts to reduce patient dose from barium enemas, particularly for the three centres involved in the present study, this is a factor worthy of attention.

8.1.6 FAE and Air-kerma at skin entrance

The large discrepancy in the value of the FAE and the air kerma at the skin entrance is demonstrated in Table 7.12 and 7.13.

FAE is the Free Air Entry dose calculated from average technique factors as described in Chapter 6. In Table 7.12 and 7.13 the values were converted to Gy to facilitate comparison using the conversion factor of 8.77 mGy/R (Kramer, 1992).

Air Kerma at Skin Entrance is a dose calculated from dose-area product readings as described earlier in Chapter 7, paragraph 7.12.

The two methods result in similar values for the radiography exposures on the overhead tube (Table 7.12). The radiography exposures on the undercouch tube have values with a difference in the order of a factor of 2. Much greater differences are shown in the values for fluoroscopy. The

overhead tube has larger FAE values by a factor in the order of 7 for the Lateral projection, 2 for the PA and 4 for the AP. The contribution to gonad dose from a lateral projection is less than for the AP or PA and is therefore of less significance to GSD. The undercouch tube has differences that is a factor of 4 for the AP, 7 for the PA and 19 for the Lateral projection. These differences indicate a possible large error in the FAE calculation due to many variables. Some of these are:

The programme used to calculate FAE is in fact an interpolation of Table B.3 of NCRP-102. This table assumes perfect circumstances which is more accurate for new equipment and can be markedly inaccurate the older the equipment becomes as output dose decreases as equipment ages. The table also cannot accommodate for the equipment variations which exist even in new x-ray equipment.

The kV was not measured in this study or in Maree's study and the table assumes the correct kV.

The table is based on a total filtration of 2.5 mm Al and this is not the case for all equipment. The correction for 3 mm Al given on a graph in the NCRP-102 indicates an error in the region of 13 %.

The programme assumes distance (SSD) as the difference between undercouch and overhead tubes and the effect of the table in the former is therefore not accounted for.

Screening is dynamic and the beam moves over an area which is constantly changing. The technique factors are therefore constantly changing and the average factors used for calculation purposes may not adequately reflect the fluctuations. In particular the mA varies as the beam moves. At times the field may even be off the patient and the mA would then be very low. The mA and kV were checked and recorded intermittently and this did not take the constant variations into account. Similarly the FAE was calculated with the assumption that the field size of 25 cm x 25 cm at the image receptor was constant which is not in fact the case. The error in dose from fluoroscopy is therefore likely to be larger than for standard radiography. Conversely the dose-area product is a direct measurement and all the variations in technique factors are automatically accounted for in the reading.

The number of units in the present study was three and measurement on a larger number of x-ray units might even out the difference between the measured and calculated doses although the indication is that it will not do so.

> Personal communication with Physicists and Inspectors at the Department of Health Technology seemed to strongly suggest that the tables can be used as a guideline only. Of particular note is that the Inspectors stated that a big discrepancy is always found between calculated and measured doses.

The sum total of these factors could result in an over-estimation of dose which is likely to explain the very high GSD from Ba E found by Maree.

Maree (1995) in his study makes the statement that most gonad dose surveys used direct measurements of entrance surface doses while in his survey published standard x-ray tube output tables for a fixed filtration and wave form were used to estimate entrance skin exposure for average technique factors. It is considered that direct measurement of skin entrance dose or the calculation of skin entrance dose from DAP-meter readings is arguably a preferable alternative to calculation of free-air entry dose from exposure factors.

Direct measurement of skin entrance dose on phantoms which simulate the particular circumstances of the x-ray examination and an average patient have benefits in terms of being closer to the real situation than calculations as well as being quicker and simpler to conduct than measurements on patients. However the value of direct measurement on patients during the x-ray examination cannot be underestimated as only then is the situation represented as it actually is. The protocol for reference doses in the UK comes as a result of *A National Survey of Doses to Patients Undergoing a Selection of Routine X-ray Examinations in English Hospitals* (Shrimpton *et al*, 1986). The comparison of FAE and air-kerma values for this study add weight to this argument and further direct measurements on patients in diagnostic radiology is recommended in South Africa.

8.1.7 Gonad dose

The air-kerma at skin entrance (Table 7.12 and 7.13) was converted to $\mu Gy \times 10^{-1}$ and used as FAE in order to calculate gonad doses, using the method as described in Chapter 6, from measured skin entry doses. The results of the gonad dose calculated for males and females for overhead and undercouch tubes for radiography (per exposure) and Fluoroscopy (total screening time) are given in Table 8.1 and 8.2. The average gonad dose for the present study using the measured air-kerma at skin entrance is given in Table 8.3. The overall error for the average gonad dose calculated from a measured skin entrance dose was estimated as being 10%. The results of the gonad doses indicate a discrepancy between the use of a calculated and measured skin entrance dose for the present study of between a factor of 3 and 7 except for the lateral fluoroscopy dose using the undercouch tube which is 20 (for comparison see Table 6.4 and 6.5). The use of the measured skin entrance dose results in an average gonad

dose that is smaller by a factor of 2.6 (for comparison see Table 6.7). The comparison of the average gonad dose (Table 8.3) with the result of Maree (Table 6.3) shows the former to be lower by a factor of 3.8. This difference in average gonad dose would clearly affect the GSD and is likely to be the major contributing factor to the result of Maree that the GSD for the white female population of South African is seven times higher than that of Great Britain (Figure 1.1).

Table 8.1: *Measured Air-kerma at skin entrance (FAE) and gonad doses for Barium Enema x-ray examinations*

OVERHEAD TUBE

		RADIOGRAPHY			FLUOROSCOPY		
Age (years)	**View**	***FAE SE*** **(mR)**	**GD male** (μ Gy x 10^{-1})	**GD female** (μ Gy x 10^{-1})	***FAE SE*** **(mR)**	**GD male** (μ Gy x 10^{-1})	**GD female** (μ Gy x 10^{-1})
	AP	422	3	117	2851	8	618
>15	PA	502	4	113	1767	4	282
	LAT	1220	3	112	1186	2	103

Table 8.2: *Measured Air-kerma at skin entrance (FAE) and gonad doses for Barium Enema x-ray examinations*

UNDERCOUCH TUBE

		RADIOGRAPHY			FLUOROSCOPY		
Age (years)	**View**	***FAE SE*** **(mR)**	**GD male** (μ Gy x 10^{-1})	**GD female** (μ Gy x 10^{-1})	***FAE SE*** **(mR)**	**GD male** (μ Gy x 10^{-1})	**GD female** (μ Gy x 10^{-1})
	AP	901	4	262	5496	8	710
>15	PA	1254	6	217	8872	9	784
	LAT	1938	2	105	1928	3	114

Table 8.3: *Average gonad dose*

av. GD male (μ Gy x 10^{-1})	**av. GD female** (μ Gy x 10^{-1})
109	**4236**

8.2 Reference doses

Optimisation of patient protection can be improved in diagnostic radiology by comparing local practice against reference levels of patient dose for a given examination (Shrimpton *et al*, 1993). In South Africa there are no protocols for appropriate sample measurements for comparison with national reference doses. The increased use of DAP-meters in x-ray departments would make it possible for dose information from diagnostic radiography to be routinely recorded. The doses could then be compared to standard reference doses in order to maintain optimum radiation protection (Wade, 1994). The measurements conducted for this study on Ba E examinations could serve as initial reference dose levels for this country. Importantly though, the extensive work on reference doses that has been carried out in the United Kingdom (UK) can be used as a guideline. These reference doses are based on the NRPB survey conducted in the early 1980s (Shrimpton *et al*, 1986), which have been adopted as the national dose standard for the United Kingdom and Europe (Wade, 1994). The reference doses for Ba E in the UK and Western Cape (WC), as calculated for this study, are given in Table 8.4.

Table 8.4: *Reference doses for Barium Enema*

Country	1st quartile	Median	3rd quartile
United Kingdom (Wade, 1994)	26 Gy cm^2	41 Gy cm^2	60 Gy cm^2
Western Cape	35 Gy cm^2	48 Gy cm^2	84 Gy cm^2

Exceeding the reference doses is considered to be an indication of poor practice and therefore requires immediate investigation (Hart *et al*, 1995). Roberts suggested that the median and quartile values are of greatest importance and that the median should be a readily achievable target dose as practices have improved over the last nine years (Roberts, 1992). Roberts goes on to say that the 3rd quartile should possibly be the level above which an investigation should be made to reduce dose and that the 1st quartile should also be an investigation level in order to evaluate that image quality at this low dose is adequate for the diagnostic purpose.

The comparison with the UK reference levels for this examination indicate that the combined doses measured during this study appear to be higher. Table 7.11 gives these results for Unit A, B and C separately and the variation between the units is obvious. As the undercouch equipment in this study indicates that the doses are higher due to equipment factors rather than technique it is advised that the

reference doses are calculated for the type of equipment in order to make them more meaningful. The digital equipment in this study demonstrated higher median values than the standard overhead equipment. This is probably related to technique rather than the equipment and it is therefore considered appropriate to recommend similar values for all overhead equipment until such time as the digital equipment can be more fully investigated.

8.3 Equipment

The three units were varied (Chapter 5, paragraphs 5.4.5.1-3) and offered the opportunity to investigate the effect of the equipment on dose to the patient. The data recorded indicates that the undercouch tube with the exposure factors used on that automatic exposure device result in higher doses to the patient. The shorter SSD and higher mAs for the radiography portion are the key differences.

Conversely the digital equipment was shown to achieve satisfactory images using a lower mAs (Figure 7.3). The result of this is that even though the number of exposures for institution B is higher than for A and C and the screening time higher than for institution A (Table 7.6) the mean dose-area product was lower for B than A by a factor of almost 1.76. This indicates that the digital equipment is an effective means of reducing the dose to the patient. The dose-area product values in Table 8.5 show that the digital equipment in this study has not resulted in the lower readings as found by Broadhead *et al.* This raises questions regarding efficiency of this particular equipment and whether it is utilised to achieve the optimum radiation dose to the patient (Broadhead *et al*, 1995). Hart *et al* make the recommendation that purchasers and users of digital fluorography equipment should check the performance of their equipment by suitable dose measurements to be sure that they are not unwittingly delivering higher doses than is achievable (Hart *et al*, 1995).

Table 8.5: *Dose-area product (Gy cm^2) for Barium Enema*
(UK data from Broadhead *et al*, 1995)

Non-digital	Mean	Median
United Kingdom	25.34	21.26
Western Cape	63.87	43.72
Digital	**Mean**	**Median**
United Kingdom	13.88	11.67
Western Cape	56.57	62.86

The statement has been made that equipment related factors have a greater influence on patient doses than does the technique used (Martin *et al*, 1994). This certainly appears to be substantiated by this study. Radiation protection of the patient therefore starts with the selection of the most dose efficient equipment. In order for the dose to be optimised the equipment needs to be regularly reviewed

and changes must be made as the developments in equipment tend to result in lower doses for better image quality. The unit in this study with the highest dose readings was also the oldest equipment. Adjustments to technique could lower the doses somewhat and at least optimise radiation protection within the limitations of the equipment. However there can be no appreciable reduction expected on this equipment.

There is not consensus on the dose from digital equipment as compared to conventional equipment. The study of Hart *et al* showed that the digital equipment delivered higher mean DAP readings at one hospital and lower readings at another hospital (Hart *et al*, 1995). The NRPB make the statement that equipment is available which provides digitally-enhanced images at a fraction of the patient dose required by conventional film-screen or film-intensifier systems (NRPB, 1990). The low mAs and high kV technique should result in lower doses from digital equipment as compared to conventional image receptor equipment. This was not the case in this study and possibly indicates that attention to technique is required.

8.4 Film-screen combination

Computed radiography (CR), such as in use at unit B, is a digital radiographic system that uses a photostimulable phosphor plate as the x-ray detector. Murphey *et al* explain that the CR system replaces the conventional film-screen combination with a storage phosphor. The phosphor imaging plate is placed in a film-screen cassette and conventional radiographic imaging equipment is used. Electrons are excited to higher energy levels by the primary incident radiation when the imaging plate is exposed. The exposed imaging plate is scanned by a helium-neon laser and when the phosphor crystals are irradiated by the secondary excitation the halide vacancies absorb energy. The trapped electrons drop to lower energy levels and light is emitted in a process referred to as photostimulable luminescence. This luminescence is captured by a photomultiplier tube and converted to an electrical signal which is then digitised. The advantages of CR include improvement in image processing, storage, retrieval and display as well as the ability to reduce radiation dose with phosphor plate technology. Reduction in radiation dose is the result of reduced exposure and fewer repeated images as the digital processing allows manipulation of contrast, detail and image noise which is partially independent of the exposure factors. Under-exposed images can be darkened and over-exposed images lightened so that the image is salvaged without exposing the patient to further radiation dose. It is suggested that the exposure reduction can be between 25 and 50 % when compared with standard film-screen technique (Murphey *et al*, 1992). This advantage was not evident for the Ba E examinations measured at Unit B in this study and further investigation of this would contribute to optimal use of this equipment.

8.5 Quality assurance

Quality assurance should be carried out in an efficient, caring and cost-effective way in order to achieve a consistently optimum image quality with minimum radiation to the patient (ISRRT, 1996). All quality assurance programmes in diagnostic radiology should therefore include regular patient dose monitoring as an essential component as it is impossible to achieve the goal of quality assurance as regards dose to the patient unless there is an operational policy which ensures that the department will work constantly towards dose reduction and thereby maintain the ALARA principle (The College of Radiographers, 1996). This must be audited and the means of audit would involve regular monitoring of the radiology practice in a particular institution. The results of such dose measurements should be compared with regional and national reference dose levels and reported back to those clinically and physically directing the medical exposures so that corrective action can be taken if necessary (Shrimpton *et al*, 1993). The control of image quality was obvious in the three institutions involved in this study however the control of radiation dose was less obvious. Attention to this aspect is imperative if the GSD for the South African population is going to drop to more acceptable levels.

In the matter of implementation of a quality assurance programme the ICRP distinguishes between:

1. *responsibility* - the duty to establish objectives, to provide measures needed to achieve those objectives and to ensure proper execution of these measures (this is essentially a prospective concept).

2. *authority* - to commit resources to meet responsibilities.

3. *accountability* - a retrospective component that requires a continuing review of performance so that failures can be identified, recurrences prevented and the attainment of objectives assessed (ICRP, 1990).

8.6 Dose reduction

The aim of this study was to evaluate the patient dose from a Ba E x-ray examination. The design did not specifically investigate the potential for reducing radiation dose to patients without adversely affecting patient care in order to make recommendations on effective methods of patient dose reduction during this particular x-ray procedure. However, as with the study of Maree, there were large variations found to occur in the same hospital and this indicates, amongst other things that there is potential for technique variation to achieve lower patient doses. A study to investigate possible ways of reducing the dose to the patient was conducted by the NRPB in Great Britain and the comment was made that the potential for patient dose reduction on a national scale was found to be high (NRPB, 1990). In this document there are comments made which refer to possible ways in which the radiation dose to patient can be reduced during a Ba E and a further study specifically aimed at this aspect for a wider range of x-ray procedures is recommended for South Africa.

In striving for a reduction in dose, the need to maintain satisfactory image quality is paramount (Roberts, 1992). This does not, however absolve the x-ray departments from their responsibility to reduce the dose. Roberts considered that the best dose-saving methods were the elimination of unnecessary examinations, reducing the number of exposures and reducing screening time.

Repeat images due to unsatisfactory image quality at first attempt is a factor in patient dose. The NRPB reported a wide variation in repeat rates (3 %-15 %) at a number of hospitals in the UK and consider that suitable quality control procedure should enable x-ray departments to have an overall repeat rate of 5 %. Table 8.6 is a summary of repeat exposures for this study and though for the Ba E only and not an overall repeat rate it implies fair quality control in the three departments. A factor of concern is the radiographer positioning error for the standard views at A. If calculated independently of the spot exposures this is an error rate of 15 %. A reduction in these repeats would contribute towards reducing the patient dose at this centre. The 7 repeats due to a dark exposure at C included 5 spot films on one very thin patient. This indicates a place for special care. The automatic exposure device is not infallible and the radiographer needs to be aware of the danger of exposure factors being too high for very thin patients.

Table 8.6: *Summary of the repeat exposures at A, B and C for this study*

	REASONS FOR REPEAT EXPOSURES						
	Exposure Dark	Exposure Pale	Film Fault	Patient Moved or Breathed	Positioning Error	Wrong Program Selected	% of Total Exposures
A		3			6	1	6.7
B	4			2			3.3
C	7		1	1			2.3
Combined	11	3	1	3	6	1	3.5

In summary the radiation dose to the patient can be reduced by (NRPB, 1990):

1. Adequate justification for the medical exposure requested which is in essence a valid clinical indication for all x-ray examinations.

2. Optimisation of x-ray equipment.

3. Improvements in radiological procedure.

The need to reduce patient doses depends on the level of risk to the individual patient and the population. In a resource-limited health service, the need will only be met if the methods and benefits of reducing the dose from medical exposure can be applied cost effectively (NRPB, 1990). There will be health care needs which

represent more cost effective ways of improving the nation's health than radiation protection. This is true for South Africa and there is much work to be done on cost effective means of dose reduction to the population in this country. Focus on justification and technique are cost effective and the optimisation of x-ray equipment a medium to long term solution. The NRPB took the fact that the mean gonadal doses delivered for the same type of examination differ by a factor of 3 to suggest that some patients are receiving doses that are unnecessarily high and that these wide variations in dose must in some part mirror the wide variations in radiographic technique. They suggest that by improving techniques would result in a substantial reduction in the collective gonadal dose to the population of Great Britain at a cost that is insignificant (Wall *et al*, 1980). The same can probably be said for South Africa.

Chapter 9

NATIONAL PROTOCOL

A national protocol for patient dose measurements in diagnostic radiology is recommended. To-date there are no national or regional standards available for South Africa and further work is required in order that norms, for patient dose from routine x-ray examinations, can be drawn up for this country. Only then will there be the appropriate attention given to doses received by the patient in the diagnostic radiology department. The NCRP make a charge to any individual who uses or supervises the use of a medical radiation source for diagnosis that he/she should understand the manner in which the radiation source operates and should know the kerma or kerma rate and the approximate dose administered to the patient for each procedure (NCRP-102, 1989). South Africa is not unique in the lack of specific information available on the doses delivered to patients and as recently as 1990 a similar statement was made about the UK. Since then a national protocol has been drawn up for the routine measurement of patient doses as part of quality assurance programmes in radiology departments in the UK (IPSM, 1992).

It may be most appropriate to commence by using the UK protocol of the NRPB as a basis for reference doses (Shrimpton *et al*, 1986) and to develop a standard specific to South Africa as data becomes available so that the impact of patient protection measures can be assessed and the guideline reference doses can be revised as necessary. The data from the NRPB national patient dose survey can provide practical reference doses for assessing performance. It is recommended that all x-ray departments should aim to achieve mean dose levels that are less than the reference doses given by the NRPB. This is particularly important because the more recent results from the UK demonstrate that lower doses than the reference doses are being achieved (Broadhead, 1995). The reference doses should not be seen as an indication of optimum performance as doses well below these may be achievable and efforts to reduce the doses further should not be relaxed because the reference levels have not been exceeded (IPSM, 1992).

A time scale could then be established and concerned departments would conduct dose measurements on selected procedures according to the South African protocol. The NRPB recommendation, in the national protocol for the UK, is to conduct measurements every three years or whenever changes to equipment or procedure occur (IPSM,1992). This is reasonable and could be similarly adopted here. Radiographers perform the majority of x-ray examinations in any department and they are in a good position to monitor the doses delivered to patients. The involvement of radiographers in the measurement process would improve their awareness of patient doses and the effectiveness of patient protection measures. Radiologists must also be closely involved as they perform many of the high dose examinations (IPSM, 1992).

It is important to choose a suitable measurement method with appropriate dose meters. The use of TLDs is suitable for plain radiography however the use of DAP-meters is considered most suitable for procedures which include screening. Wade suggested that as dose area product meters become more widely available they could be used for recording information on standard radiographic views as well. This would be simpler and therefore a more satisfactory alternative to TLDs (Wade, 1994). Whatever method is selected it is important that the calibration is done correctly and regularly checked. The use of DAP-meters and reference doses recorded directly as Gy cm^2 ensures immediate knowledge of results and this method is recommended as a very effective way of ensuring the ALARA principle is adhered to. However, the control of the measurements needs to be centralised for the best benefit as only then will the data be constantly up-dated in line with national changes and international norms.

All departments participating in the monitoring process must know the results as soon as possible and the time delay should be kept to a minimum if the response is to be effective. The responsible radiation protection personnel must be informed of the results and be encouraged to act on the results, especially if the doses are higher than the recommended standard. These are the professionals who can ensure that the dose to individual patients and the population as a whole is kept as low as possible.

Methods for monitoring patient doses must be easily carried out by radiographers with guidance from the medical physicists (Wall, 1996). Record sheets need to be kept simple with the minimum data to be recorded by the radiographer in order to enhance accuracy and encourage participation. The data that needs to be included is the procedure being done, selection of screening kVp and mA (unfortunately these are not always displayed or easily visible), total screening time, details of projection and the exposure factors, DAP-meter reading and minimum patient information (age, gender, mass). The race need not be recorded as it is not a factor in compiling reference doses for given examinations or in comparing doses to reference levels. Completed data sheets should ideally be forwarded to a central office for processing and analysis. A report would be prepared comparing the departments involved, with confidentiality being maintained, and the results would be sent out so that the staff of the radiology departments have a clear indication of the doses being delivered to their patients and how they compare with the national norms. The Department of Health Technology is the appropriate office to control such a process in this country, however the infrastructure may not allow for this at present. The IPSM also recommends that the relevant details of the estimation of the radiation dose should be inserted into the patient's records (IPSM, 1992).

The quantities recommended for measurement by the IPSM are:

1. surface entrance dose for individual radiographs

2. dose-area product for complete examinations

It is recognised that other dose quantities may be more closely related to the radiation risk to the patient however it is most beneficial to select quantities that can be obtained by means of simple direct measurement. Valid comparisons can then be made with previous measurements at the same facility, other facilities and with the national reference doses (IPSM, 1992). The dose-area product option for complex examination is an optimistic option and until such time as it is possible to establish this as a routine there should at least be some method of monitoring all procedures involving fluoroscopy with or without radiographs.

Departments should be encouraged to include DAP-meters when purchasing new screening equipment. The inclusion of dedicated dose meters, as a permanent fixture on screening units, would encourage the routine monitoring of dose measurements and assist in data gathering in order to establish norms in routine procedures carried out in this country and ultimately the radiation dose to each individual patient and the population would be optimised. However the expense of DAP-meters dedicated to a particular unit could delay the monitoring process and in fact one DAP-meter, or two in large departments, would facilitate the monitoring of equipment to be done on a rotation basis.

The reference doses will assist in two ways:

1. The calculation of doses to individual patients when this is required for radiation protection purposes. Attention is drawn to the fact that all the uncertainties in the estimation of dose for individuals patients is difficult to quantify. The relevance of many of these sources of error will be reduced when considering large numbers of measurements on a heterogeneous population of patients, involving varied physique and clinical requirements and carried out in many departments. Under these circumstances, it is assumed that the mean values of organ doses discussed should be representative of those for an average adult patient.

2. Optimisation of radiation protection for the patient in radiology as it is a fact that the potential for dose saving in medical irradiation is large and warrants attention. This document has only considered one radiology examination and has identified several aspects that justify further study. It is hoped that work in the arena of dose measurement to the patient in diagnostic radiology will continue in South Africa and that the ALARA principle will be applied more conscientiously.

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Appendix A

A1 Sample of blank record sheet

A2 Sample of completed record sheet

A3 DAP-meter readings on Unit A, B and C for reliability testing

Appendix A1

Record of Measurements

BARIUM ENEMA X-RAY EXAMINATIONS

Institution:______________________ Unit :______________________

Date :______________________ Filtration:______________________

Channel :______________________ SID :______________________

Patient	Age	Weight	Male (M)	Asian(A)	Screening		Radiographs				DAP Meter Reading		Comments
number	(years)	(kg)	Female (F)	Black(B)	Time	Exposure	View	Cassette	Exposure	Total	Total Time	Gy cm^2	
				Coloured(C)	Unit	Factors		Size	Factors	Exposures	(in sec.)		
				White(W)	(in min.)	kV mA			kV mAs				

Appendix A2

Record of Measurements

BARIUM ENEMA X-RAY EXAMINATIONS

Institution : C
Date : 15/04/97
Channel : 1

Unit : S
Filtration: 3.5 mm Al
SID : 108 cm

Patient	Age	Weight	Male (M)	Asian(A)	Screening		Radiographs				DAP Meter Reading		Comments
number	(years)	(kg)	Female (F)	Black(B)	Time	Exposure	View	Cassette	Exposure	Total	Total Time	Gy cm^2	
				Coloured(C)	Unit	Factors		Size	Factors	Exposures	(in sec.)		
				White(W)	(in min.)	kV mA			kV mAs				
17	62	70	M	B	3.3	107 4.0	Lateral	18x24	117 86.7	12	290	31.84	Dr Y
						105 3.4	AP Obl	24x30	109 15.2				Double
						90 2.2	AP Obl	24x30	109 24				Contrast
						98 2.8	PA Obl	30x24	109 29.4				
							PA 30°↓	24x30	109 24.6				
					0.6	2.950	AP Obl	24x30	109 17.7				}split
						(DAP)	AP Obl	24x30	109 66.3				}
							AP Obl (E)	24x30	109 14.4				
							AP (E)	35x35	109 12.4				SEP
							AP Obl (E)	24x30	109 16.6				AP:27 cm
							AP	35x43	109 11.8				PA:24.5 cm
							PA	35x43	109 20.3				LAT:32 cm
													Plus: 8 cm
								Mean kV	109.67				(for SSD)
								Mean mAs	28.28				

Appendix A3

Reliability test for DAP-meter and Unit A

Overhead tube - Radiography					MEAN DAP (Gy cm^2)	STDEV	% STDEV
80kV	10 mAs						
0.792	0.785	0.791	0.792	0.790	0.790	0.0026	0.33
80 kV	20 mAs						
1.583	1.584	1.582	1.584	1.583	1.583	0.0007	0.04
80kV	40 mAs						
3.101	3.107	3.110	3.119	3.109	3.109	0.0058	O.19
Undercouch tube - Radiography							
80 kV	20 mAs						
0.786	0.773	0.778	0.766	0.776	0.776	0.0065	0.84
80 kV	40 mAs						
1.554	1.556	1.555	1.561	1.563	1.558	0.0035	0.23
80 kV	50 mAs						
1.959	1.96	1.958	1.956	1.960	1.959	0.0015	0.08
Undercouch tube - Screening							
70 kV	Colon Programme		(per minute)				
0.144	0.148	0.144	0.152	0.148	0.147	0.0030	2.04

Reliability test for DAP-meter and Unit B

Overhead tube - Radiography					MEAN DAP ($Gy\ cm^2$)	STDEV	% STDEV
80 kV	80 mAs						
0.281	0.282	0.286	0.282	0.281	0.282	0.0021	0.75
80 kV	40 mAs						
0.140	0.139	0.139	0.144	0.147	0.142	0.0036	2.54
80 kV	20 mAs						
0.069	0.073	0.073	0.073	0.073	0.072	0.0018	2.5
Overhead tube - Screening							
57 kVun	0.5 mA	(per minute)					
0.052	0.055	0.052	0.052	0.054	0.053	0.0014	2.64

Reliability test for DAP-meter and Unit C

Overhead tube - Radiography					MEAN DAP (Gy cm^2)	STDEV	% STDEV
80 kV	10 mAs						
0.451	0.460	0.461	0.461	0.46	0.459	0.0043	0.94
80 kV	20 mAs						
0.925	0.927	0.928	0.926	0.928	0.927	0.0013	0.14
80 kV	40 mAs						
1.85	1.858	1.856	1.858	1.857	1.856	0.0033	0.18
Overhead tube - Screening							
50 kV	0.3 mA	(per minute)					
0.232	0.232	0.232	0.236	0.232	0.233	0.0018	0.77